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COLOUR FLOODLIGHTING OF THE GARRICK THEATRE, SOUTHPORT, BY "OSIRA" FLOODLIGHTING LAMPS.
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G.E.C. Journal

VOL. V. NOVEMBER, 1934. No. 4.

Some Applications of X-ray Crystallography to Industry.

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The discovery of the regular arrangement of atoms and molecules in solid bodies over twenty years ago was one of great importance to physical and chemical science. Since that time, the study of this subject by means of X-rays has made enormous advances, and as a result there have arisen important technical applications. In the present article, the underlying principles of the subject are briefly explained, and illustrations are given of industrial applications covering such subjects as the behaviour of refractory materials, the manufacture of glass, wire drawing, radio valves and hot cathode discharge tubes.

1. INTRODUCTORY.

THE discovery of X-rays by Röntgen towards the close of the nineteenth century is one of the landmarks of physical science, and everyone is familiar with at least one use to which the rays have been put. There are in fact two major applications of X-rays, the radiographic and the crystallographic. The radiographic method may be used either for the detection of flaws in dense pieces of metal such as machine parts, or for the diagnosis of obscure structural ailments of the human body. In either case the general principle is the same. As the radiographic applications have been dealt with in a recent article[1] in this journal there is no need for elaboration here. The crystallographic application consists in using X-rays to determine the arrangements of atoms and molecules in ordinary solid bodies. It is thus readily distinguishable from the radiographic method, which is concerned only with differences of macrostructure. One of the most important applications of the crystallographic method uses the atomic arrangement of a solid body as a kind of identification mark, a clue, which leads to the recognition of the form and perhaps the nature of any particular substance. Before, however, the physical principles of the subject can be considered it is necessary to revert for a moment to some of the properties of the X-rays themselves.

In order that X-rays may show up structural faults in a large piece of steel it follows that the radiation must have great penetrating power, and it has long been known that the penetrating power increases rapidly as the wave-length decreases. X-rays are fundamentally of the same nature as ordinary light, heat or wireless waves. They differ only in their "colour." There is in fact a continuous gradation from one end of the scale to the other. Such X-rays as are to be considered in this article are waves with their crests about 10^{-8} cms. apart; the wavelengths of visible light are of the order of 5×10^{-5} cms.

The Diffraction of X-rays by Crystals.

Roughly three hundred years ago Newton and Grimaldo noticed that the shadows of straight objects were not quite as they would have been had the light travelled in absolutely straight lines. Much later it was found that light reflected from a plate of glass ruled with very close fine lines bunched itself into certain definite directions, depending on the colour of the light and the distance apart of the lines on the plate. It was found that the lines had to be about the same distance apart as the crests in the waves of light if the effect was to be observed. This second effect, which is due to the same causes as the first, was called the diffraction of light and the ruled plate of glass a diffraction-

grating. Up to about 1910 no one was yet sure whether X-rays could be considered as waves in the ether or as particles. Bravais, Barlow, and Pope, had built up ideas of crystal structure which depended for their success on the regular arrangement of molecules in three dimensions. In the year 1912 von Laue realised that the earth must be full of atomic or molecular diffraction gratings of

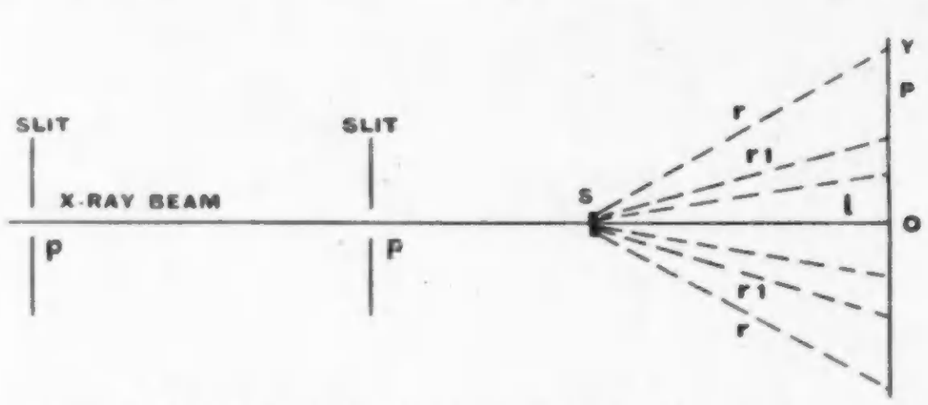


Fig. 1.—The diffraction of X-rays by a powdered crystal.

probably the correct spacings to diffract X-ray waves if such existed. An experiment was tried by Friedrich and Knipping in order to verify this and was a brilliant success. Laue's theory of the diffraction effect was much simplified by W. L. Bragg and used by him in the determination of the atomic arrangements in crystals. The significance of these discoveries in the realms of physics and chemistry cannot be dealt with here, but a most lucid and admirable survey of the whole subject has recently been given by W. L. Bragg.[2]

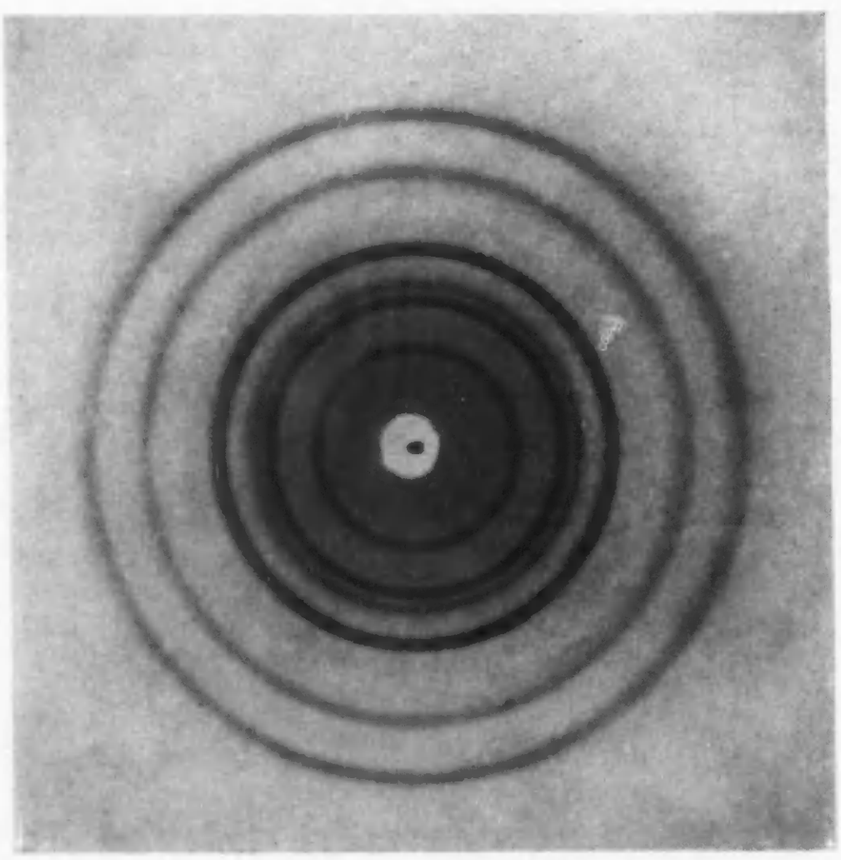


Fig. 2.—Powdered crystal photograph of alumina.

The Bragg Law states the conditions under which X-rays of a given wavelength λ incident on a crystal face at glancing angle θ, will be reflected by the atomic planes of spacing d.

It is in fact

$$2d \sin \theta = m\lambda \quad \ldots\ldots\ldots\ldots \quad (1)$$

for an m^{th} order spectrum.

Unless, therefore, m is known, knowledge of λ and θ, only allows the determination of the values of d/m. This alone is sufficient to identify a known pattern; much more information is required before the atomic or molecular arrangement can be determined. Usually, such information is acquired by a variety of methods.

Generally, most solid bodies are crystalline or micro-crystalline. Naturally, the degree of crystallisation will differ and in some cases the crystals may be so small that only X-ray examination will show up the degree of regular atomic arrangement. In most industrial problems involving X-ray analysis, the investigator is usually concerned with the identification of the form or nature of a given material rather than with detailed analyses of crystal structure. This will be apparent in the later sections.

Experimental Methods for the Determination of Crystal Structure.

There are four main methods in use for the determination of crystal structure by means of X-rays. These are:

(1) Laue method.
(2) X-ray spectrometer method.
(3a) Rotating-crystal method.
(3b) Weissenberg goniometer method.
(4) Powdered crystal method.

Of these, the powdered-crystal method is the most widely used in industry. Combinations of (3a) with (4) are also of importance, and the Laue method has certain limited applications. In the present article almost all of the applications will be concerned with the powdered crystal method, which will now be described.

2. THE POWDERED CRYSTAL METHOD.

If a small quantity of some powdered crystalline material be attached, for example, to a thin sheet of tissue-paper, and placed in a monochromatic beam of X-rays, it is clear that many of the particles will be so disposed as to reflect the X-rays according to the conditions of equation (1). With a single crystal it would be necessary to determine appropriate azimuths by experiment. An X-ray beam defined by circular pinholes *pp* as in fig. 1, will be diffracted by the unoriented particles of the specimen *S* along the surfaces of a family of cones *s*, *r*, *r*, etc. These cones intersect a photographic plate *P* placed at right angles to the incident beam in a series of unbroken circular rings. Consider the diffracted ray *s r*, and let the distance *SO* be *l* and distance *OY* be *y*.

$$\hat{YSO} = \text{Angle of diffraction.}$$
$$= 2\theta$$
$$\frac{YO}{OS} = \frac{y}{l} = \tan 2\theta$$

$$2\theta = \tan^{-1}\frac{y}{l} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

But $2d \sin\theta = m\lambda$

$$\text{Hence } \frac{d}{m} = \frac{\lambda}{2\sin\theta} = \frac{\lambda}{2\sin(\frac{1}{2}\tan^{-1}\frac{y}{l})} \quad \ldots\ldots \quad (3)$$

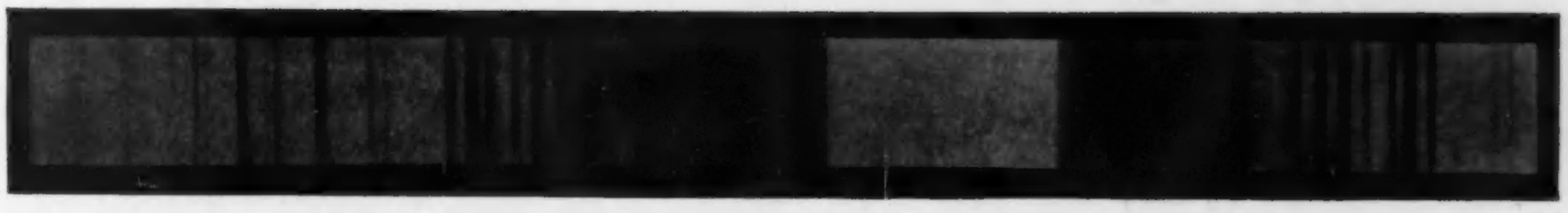


Fig. 3.—Powdered crystal photograph of mullite.

Measurement of the photographic image enables us, therefore, to determine d/m, the ratio of the distance between given sets of atomic planes to the order of the spectrum. If the specimen is of an unknown nature, this may give sufficient information to identify it. Sometimes the information would be a great help in determining the actual arrangement of the atoms, if this is required. Usually, in industrial problems, this is not necessary, and in general the determination of the structure requires knowledge of intensities and clues to the absence of certain spectra, which can only be obtained by use of methods (2) and (3).

By the use of a rectangular slit system the rings of the pinhole method may be turned into slightly curved lines. As an example of this, figs. 2 and 3 show two powdered-crystal photographs of alumina and the aluminium silicate mullite.

The K-α rays of copper and molybdenum are perhaps the most useful radiations in this type of work, but special circumstances, such as the nearness of wave-length of the incident radiation to an absorption edge of the specimen, may indicate another choice. Either cold cathode X-ray tubes of the gas-leak type, or the hot cathode tungsten filament X-ray tube may be used. The latter is probably steadier, but requires the maintenance of a fairly high vacuum over long periods of time. In fig. 4 is shown an X-ray tube and type of camera, used in many investigations in the Research Laboratories of the G.E.C. The X-ray tube has four windows, so that it is possible to investigate four different specimens simultaneously.

Fig. 4.—Hot cathode X-ray tube showing water cooling system and camera in position.

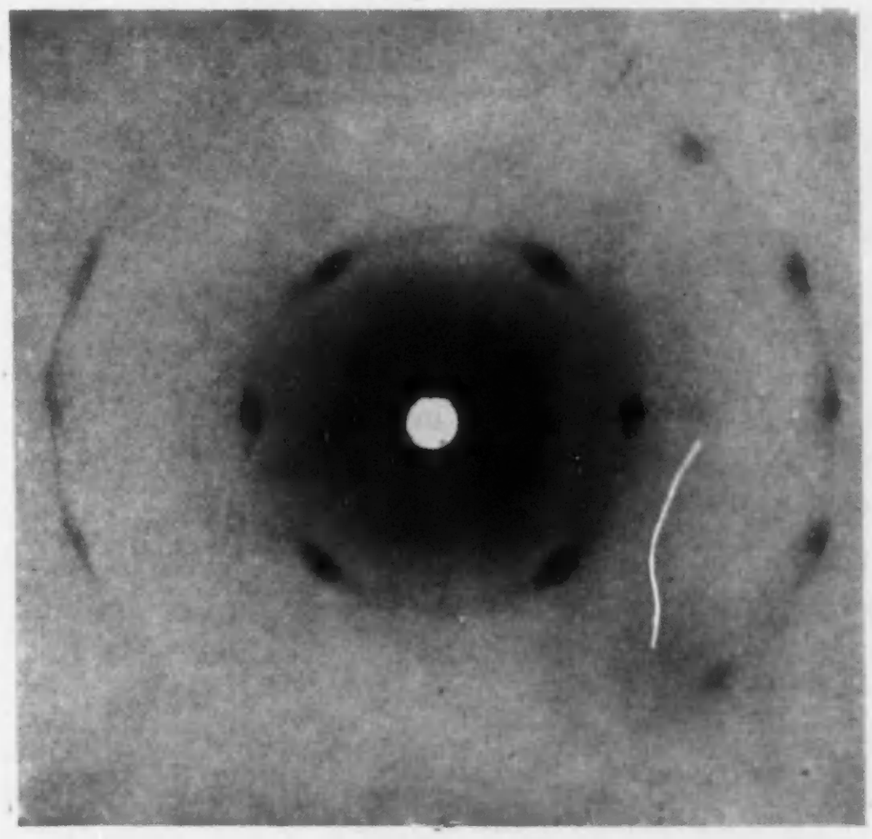


Fig. 5.—Orientation diagram of tungsten wire, axis vertical.

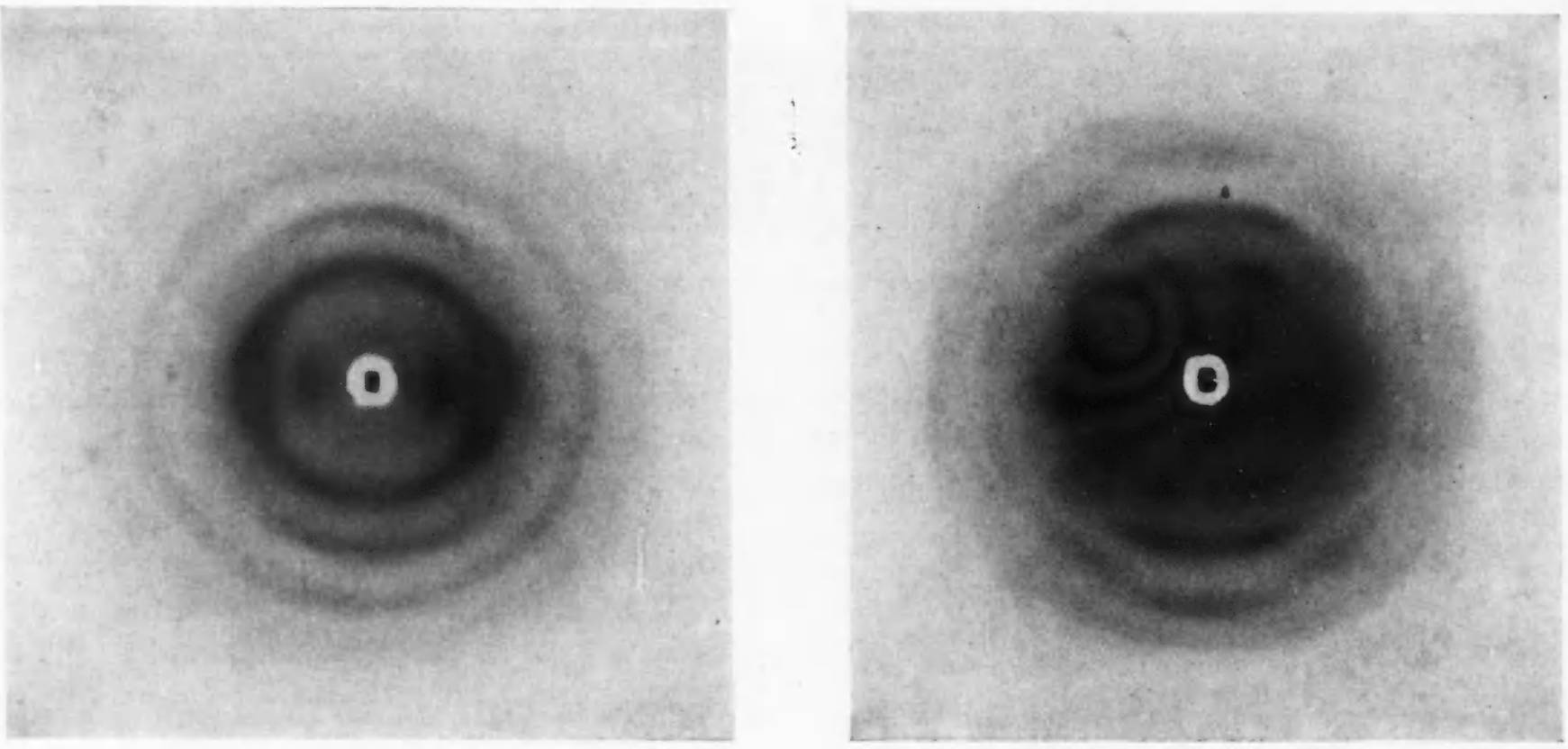
3. THE VARIOUS TYPES OF INDUSTRIAL PROBLEM.

(*i*) *The Investigation of the Physical State of a Substance.*

Wire Drawing.

Apart from the obvious division of matter into solids, liquids and gases, there are many special forms which a substance may assume in the solid state, which may be of importance industrially.

The tensile strength of a metal wire or silk fibre is a function of the degree of orientation of the crystals. The more crystals that are aligned parallel to the major axis the stronger the fibre. The powdered-crystal method gives rise to complete diffraction rings so long as the crystals are unoriented. If all the crystals in a tungsten wire have a particular axis parallel to the wire axis, an X-ray photograph taken with the beam perpendicular to the wire axis will be similar to that obtained by rotating a small single crystal about the same axis. The diffracted radiation concentrates into certain special directions so that the rings now appear broken. The spots on the different rings can in fact be related to one another by hyperbolas, which are the well known "layer lines" of rotation photographs. In fig. 5 is reproduced a photograph of a tungsten wire taken perpendicular to the wire axis, and it can be shown that the photograph is almost identical with that which would be obtained by rotating a small single crystal about its (110) axis. The process of drawing the wire through various dies has caused slipping of the crystals in a definite direction and this results in the high degree of alignment seen in the figure. The rolling of metal into sheets produces a similar effect, and the degree of orientation is again an important factor in determining the physical properties of the material. Such correlation of physical properties and alignment of the crystals is not confined to the inorganic world; much valuable work has been done in the artificial silk industry. The properties of this material depend to some extent on the degree of alignment of the minute fibres or micelles which go to make the complete thread. In figs. 6a and 6b are contrasted the X-ray photographs of two specimens differing in this respect.

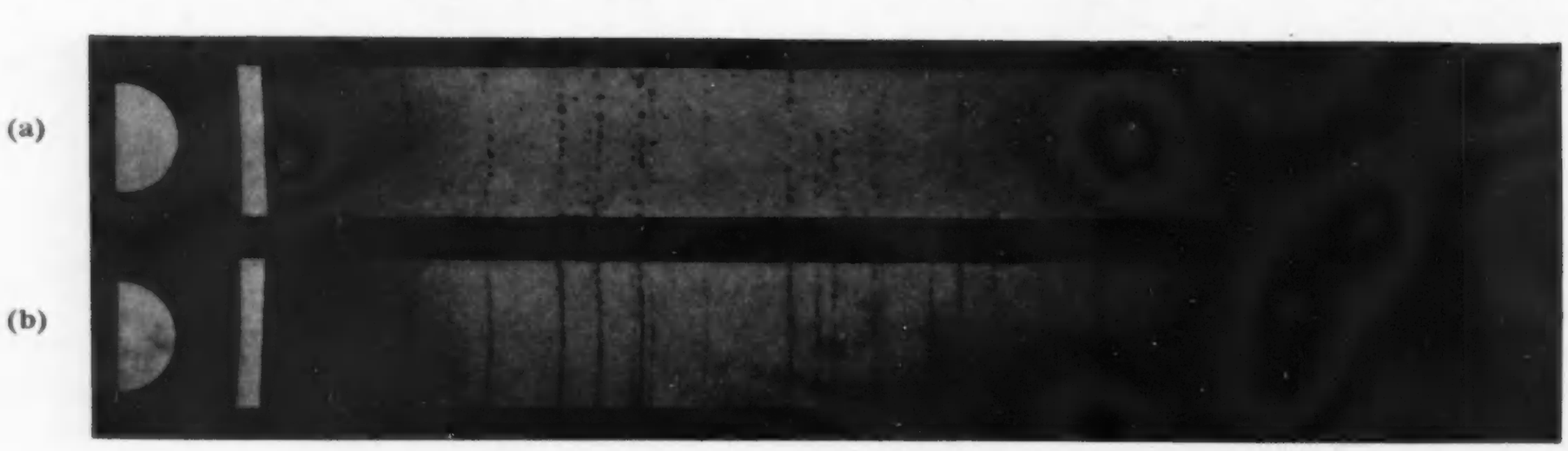


(a) (b)

Fig. 6.—Contrasting two artificial silks of differing degrees of orientation.

Crystalline Form.

The mechanical processes necessary to produce metal wire and sheet, in spite of their effect on the relative disposition of the crystals, have usually left the atomic arrangement in any given crystal unchanged. There are many problems in which it is necessary to know the precise form of a particular substance. For example, in some refractory bodies containing silica, it is important that there should be only one crystalline modification throughout the



(a)

(b)

Fig. 7.—Powdered crystal photographs of wurtzite: (a) coarse-grained specimen; (b) the same specimen rotated during exposure to X-rays.

material, namely cristobalite. The presence of the quartz modification in any part of the body would set up strains due to differences in thermal expansion, and this would adversely affect the life of the material.

Effect of Grinding Crystal Powders.

Again, some solids change their crystalline form, or show lattice distortion, on grinding into a fine powder. Such a substance is wurtzite. In order to obtain a satisfactory powder photograph of the original material the specimen is rotated so as to present the various correct diffraction angles to the beam. Severe grinding treatment is thus avoided. Two photographs of wurtzite are shown in fig. 7. In (*a*) the coarsely ground specimen remains fixed in position. In (*b*) the same specimen has been rotated about an axis perpendicular to the X-ray beam. This is an example of technique which has sometimes to be made use of, in order that the evidence should not be distorted in any way by subsequent treatment of the material.

Particle Size.

The state of subdivision of a powder may frequently be of importance, and it is possible by use of the X-ray method to place a series of steel samples or carbons of various kinds, such as carbon blacks, in correct order of ultimate particle size. Particles lying between the limits of 10^{-3} and 10^{-5} cms. give rise to fairly sharp lines on an X-ray "powder" pattern. If the particle size be reduced to a still smaller value, the crystalline

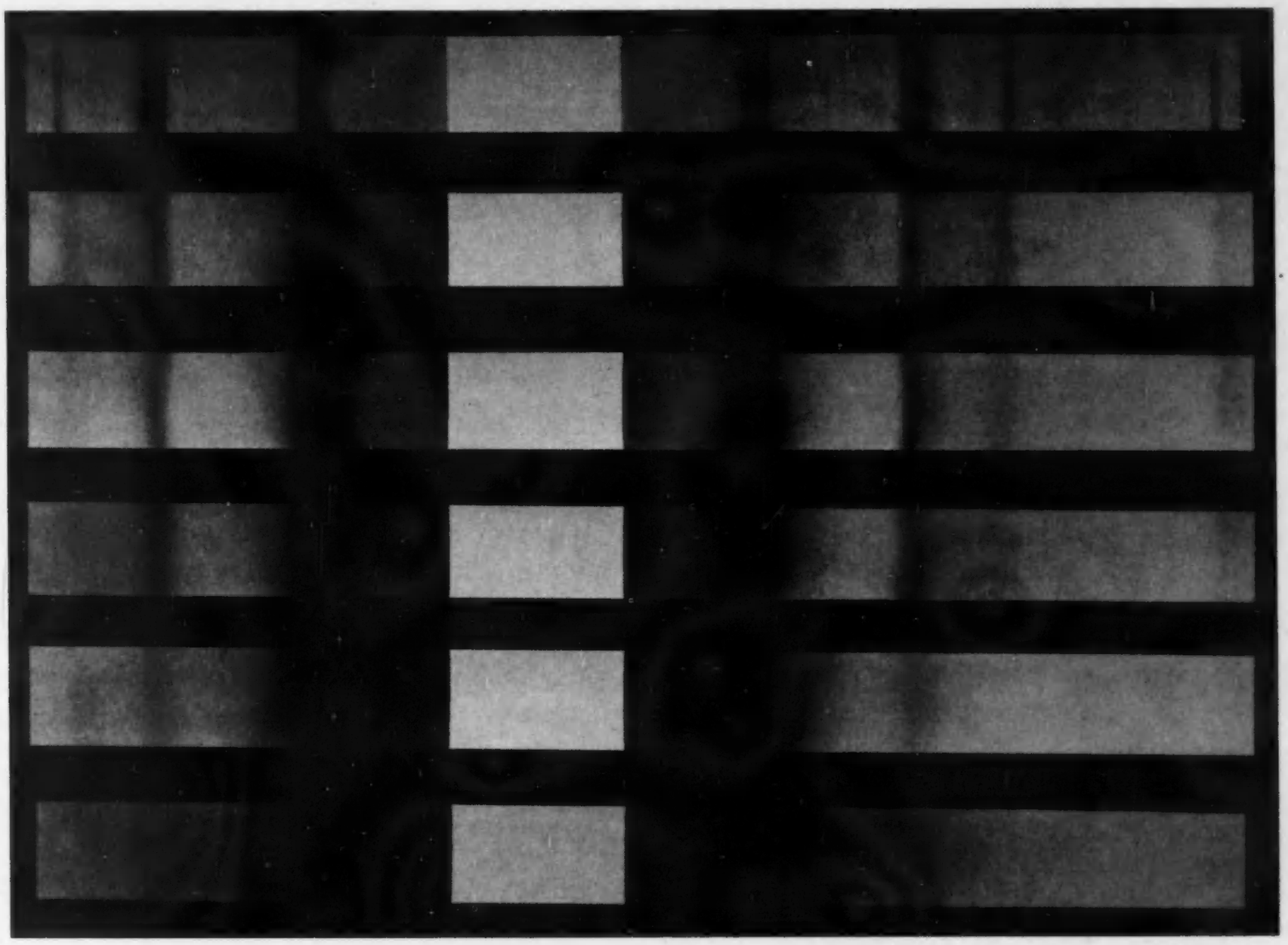


Fig. 8.—X-ray photographs of graphite and various carbon blacks.

Fig. 9.—Contrasting patterns of good and bad oxide cathodes: (a) shows one solid solution; (b) two solid solutions.

diffraction grating becomes so small that high resolution is unobtainable, and the lines on the photograph broaden out. This effect is clearly shown in fig. 8 for carbon blacks. This illustration is similar to one given in the article by the late W. E. Downey in the *G.E.C. Journal*, Vol. II. No. 3, Nov. 1931. Again, it is an easy matter to follow the effect of various heat treatments on crystal growth. As crystal size is frequently linked in a perfectly definite way with the hardness of a material, there is no need to emphasize the importance of this application.

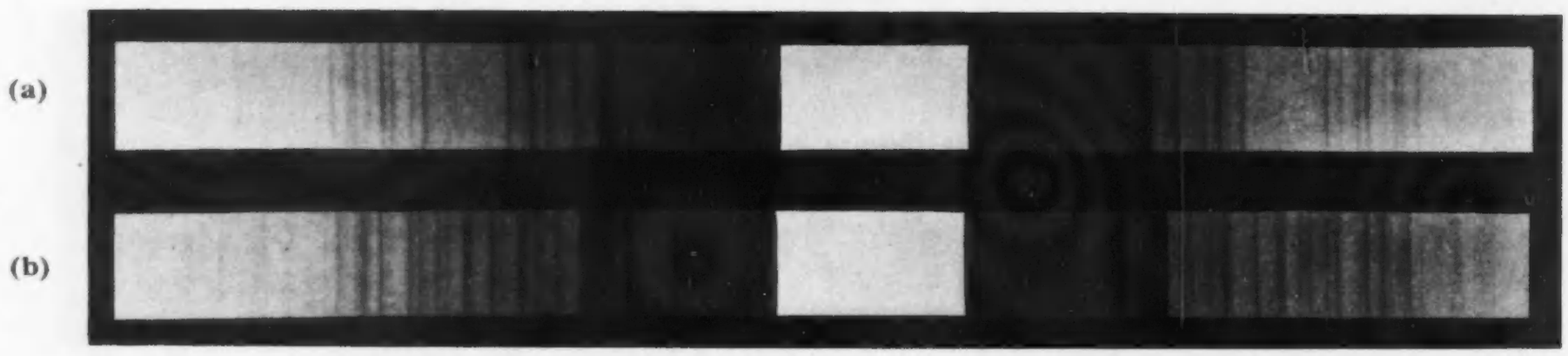


Fig. 10.—X-ray patterns of barium silicates : (a) $2BaO.1SiO_2$; (b) $3BaO.1SiO_2$.

Applications to Thermionic Cathodes.

Both wireless receiving valves and hot cathode discharge tubes depend to a large extent on the type of cathode that is used as emitter of electrons. In the receiving valve the emitting cathode takes the form of a nickel wire coated, initially, with a solid solution of barium and strontium carbonates ; in the hot cathode discharge tube the cathode frequently consists of a hard sintered rod of some barium compound placed inside and in close contact with a tungsten helix. In the case of the receiving valve cathode, the process of activation during manufacture changes the nature of the cathode coating. In the hot cathode tube, the nature of the sintered rod remains essentially unchanged during the pumping of the tube. The performance of the two types of emitter depends both on the nature of the chemical elements present and on the way in which they are combined. Thus in the receiving valve, X-ray examination of the cathodes while still in vacuo has shown that the solid solution of barium and strontium carbonates usually reduces to a solid solution of barium and strontium oxides. Sometimes, however, two distinct solid solutions are present and in this case the emission current differs from that obtained when one phase only is present (see fig. 9). Another side of the problem is concerned with examination of cathodes which have been run for a considerable time or, alternatively, flashed at high temperature. In these cases it has been shown that the much reduced emission was due to a preferential loss of barium oxide. (6). In the receiving valve it is clear that so long as the coating has the form of a solid solution of carbonates when mounted in the bulb, the subsequent behaviour should depend entirely on the treatment received on the pump.

While the same kind of argument would also apply in a limited way to the cathodes used in the "Osira" street lighting and floodlighting tubes, it would be more accurate to say that the treatment the cathode receives before mounting in the tube is much more important, since this determines the nature of the compounds formed. For some of these discharge tubes the initial cathode material consists of a mixture of barium carbonate with silica. This mixture may be extruded in the form of rods by adding a suitable binding agent. The next part of the treatment consists in furnacing these rods to a high temperature. It has been found by X-ray analysis that the conditions of furnacing control the nature of the compounds formed. Thus the orthosilicate $2BaO.1SiO_2$ may be formed, or alternatively a new compound, $3BaO.1SiO_2$. Without the help of X-ray analysis it would have been impossible to arrive at a proper understanding of the reactions which were taking place. Fig. 10 illustrates this problem by showing the X-ray patterns given by the individual compounds.

(ii) *Chemical Applications.*

In a subject of this kind it is difficult to draw the dividing line between physics and chemistry, but there are two types of application which may justly be described as chemical. Spectroscopic and chemical analysis can only give the amounts of various elements in a given sample ; X-ray diffraction methods can reveal the nature of the association, whether an element is present in the form of an oxide or a sulphide, for example. This is because no two substances give rise to the same X-ray pattern. Every atom has a different effective diameter and a different power of scattering X-rays. Every substance, therefore, possesses an identification mark in the form of its X-ray pattern. This method may very usefully be employed for the routine identification of unknown substances. This implies, of course, a wide knowledge of the type of X-ray pattern likely to be obtained. In a given industry, however, the expert may soon learn to recognise the type of substance likely to be found

in any given investigation. In any case the spectroscopist or the chemist can usually identify the elements. The following example indicates how X-ray methods can be applied in solving a certain type of problem which could not be tackled by ordinary analytical methods.

Opal Glasses.

The nature of the particles that give to opal glasses their peculiar property of scattering light had been discussed for many years, and the chemical or spectroscopic method was not of particular value because the glass itself probably contained the same elements, if not the same compounds, in non-crystalline form. The success of the X-ray method in identifying the scattering particles depended on the fact that the bulk of the glass gave rise to an entirely different type of pattern in the form of one or more broad bands, such as can be seen in fig. 11.[3] An opal glass, however, shows in addition to these bands certain sharp lines characteristic of normal crystalline material[4]. In the particular cases examined, it was found by a process of elimination, that these lines were in every case due to sodium fluoride or calcium fluoride, or to a mixture of these. This result is illustrated in fig. 12. By making up standard samples it was also possible to determine the relative proportions of the two fluorides in any given sample.

Selenium Ruby Glasses.

A somewhat similar problem existed in the case of the so-called selenium ruby glasses. Clear glass can be coloured orange or red by the addition of cadmium sulphide and selenium to the glass during manufacture. After the glass tubing has been drawn it is subjected to a definite temperature treatment, in order to "develop" the colour of the glass. Two types of specimen were found, those whose colour was independent of the temperature treatment and those whose colour varied with the treatment. X-ray examination of the glasses revealed that the particles giving rise to the colour were in all cases solid solutions of cadmium sulphide and cadmium selenide.

The variable set of specimens, however, was found to contain less cadmium than the stable ones. Thus the provision of an adequate amount of cadmium sulphide in the original mixture was found to be a satisfactory way out of the manufacturing difficulty.

(iii) *Micro-chemical Problems.*

In addition to problems of this kind there are others which may perhaps be described as micro-chemical in nature. In the problems of opal glasses and ruby glasses there was always a large quantity of material available for examination and the percentage of crystalline scattering material in the glass was sufficient for the X-ray patterns to show up with moderate clarity above the background of the general glass pattern. In other problems there is frequently only a small amount of material available. In a gasfilled or a vacuum lamp, for example, there may be certain extraneous materials which are the cause of chemical reactions. These may result in the deposition of a small deposit on some part of the lamp. Here the chemist is in a real difficulty because of the minute amount of material available for examination. The spectroscopist is therefore usually asked to identify the elements present, and the X-ray method is used to identify the compound. To take a particular case. In gasfilled tungsten lamps designed to run at a particularly high efficiency, the temperature of the tungsten filament is sufficient to react with the nitrogen usually contained in the filling gas. A brown deposit of tungsten nitride is formed on the bulb, and this can be identified by means of X-rays[5].

The method has also been used to show up the details of the well-known water vapour reaction in tungsten lamps, in which the filament is ultimately destroyed at certain points by the interaction of oxygen and tungsten. It might have been expected that convection currents would carry a certain amount of the oxide on to the cooler bulb surface, together with some metallic tungsten formed by reduction of oxide at the cooler portions of the filament. X-ray examination of the black deposit shows in fact that only tungsten is deposited and this must be due to the very effective reducing action of atomic hydrogen[5].

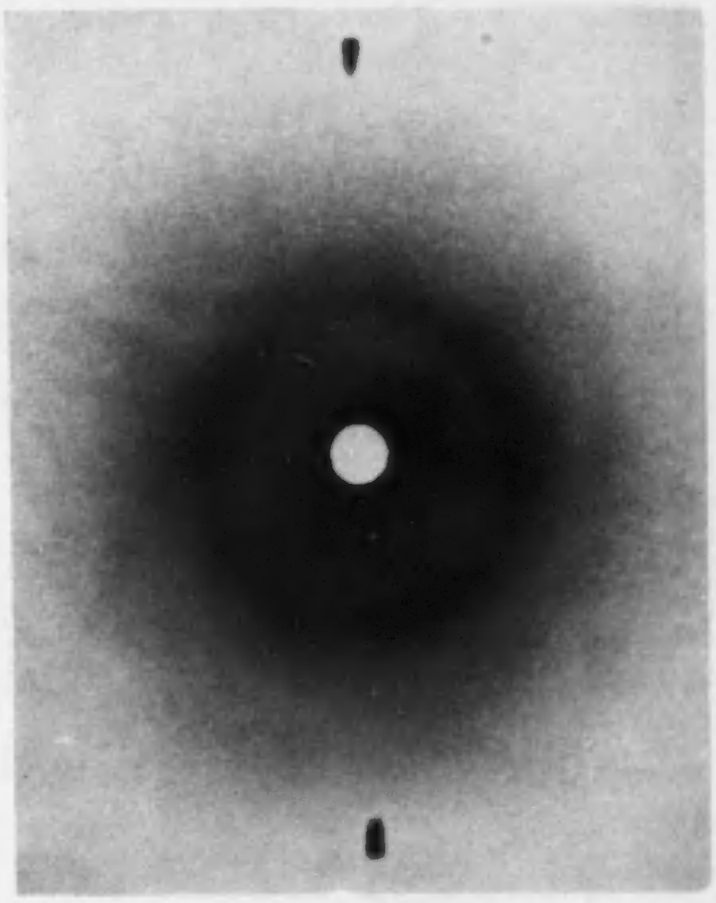


Fig. 11.—X-ray photograph of lead metasilicate glass.

4. GENERAL REMARKS.

It would be possible to multiply the number of interesting applications of X-ray crystallography to

industry almost indefinitely, but perhaps enough have been given here to indicate the types of problem frequently encountered. There are one or two remarks of a general nature, however, which should be made. In the first place the application of X-ray crystallography to industry is not by any means an entirely routine process. Very frequently new techniques have to be developed in order to examine the materials under conditions having some relevance to the main part of the experimental work. For example, if the properties of certain materials are to be studied at a temperature of 1000°C., it may be of little use to examine the diffraction pattern given by the substance at room temperature; special small furnaces may have to be developed, in which the examination may be carried out.

A second point of importance is one which is no particular perquisite of the X-ray method; the diffraction patterns frequently reveal unexpected complications in a problem. Instead of finding one simple pattern, two or three may be found to be superposed. These, in turn, may give fresh ideas for tackling the difficulties. Even if the ideas obtained from a study of the X-ray patterns are wrong, they certainly suggest new lines of experiment.

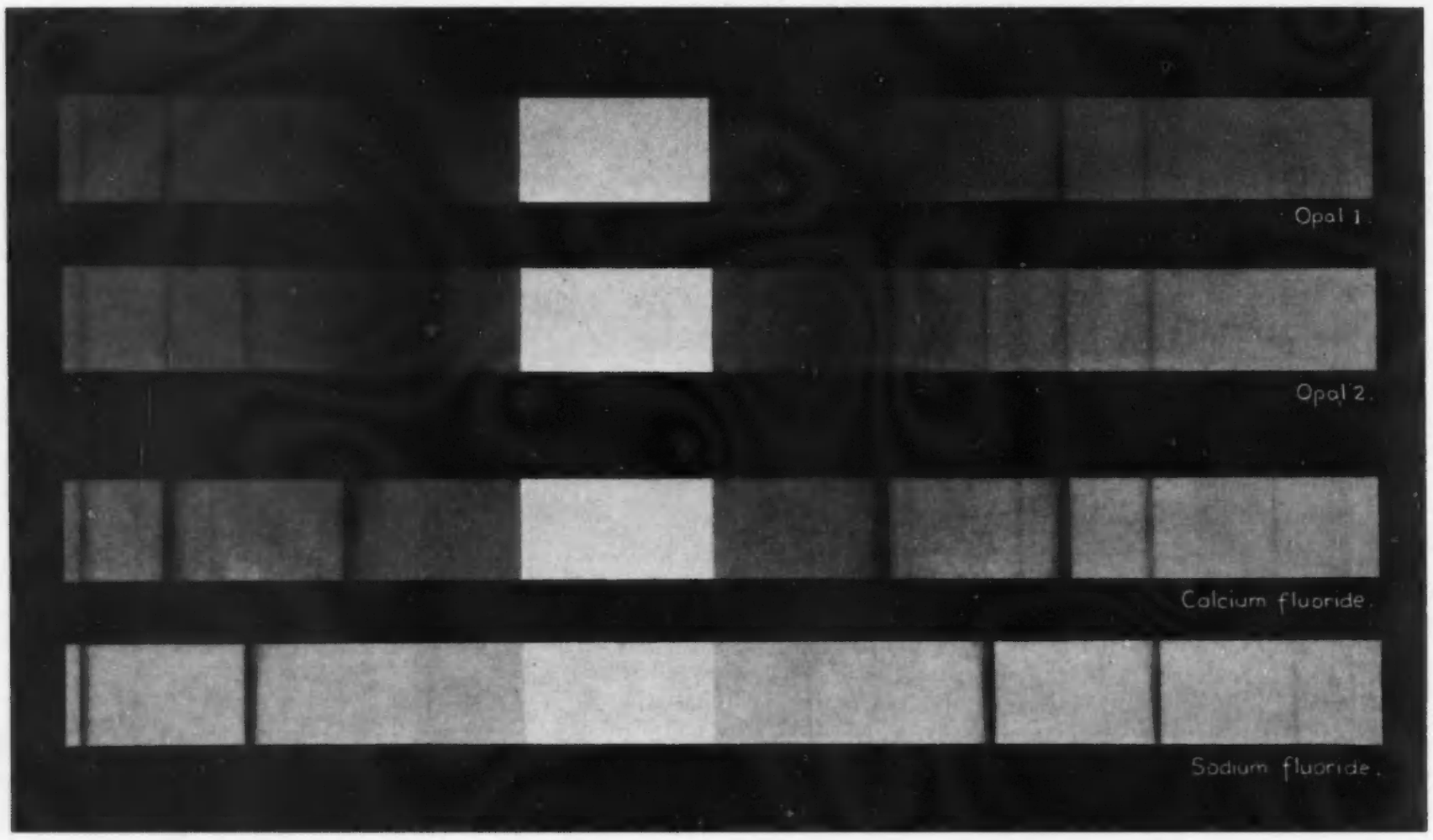


Fig. 12.—X-ray powder patterns showing nature of particles in two opal glasses. Opal 1.—Mainly calcium fluoride; Opal 2.—Mixture of sodium and calcium fluorides.

ELECTRON-DIFFRACTION.

Much has been written, during the last few years, about the diffraction of electrons by crystalline bodies, and it may be appropriate to conclude this article with a word about the possible applications of this technique to industry, since it depends on analogous phenomena and supplements X-ray methods. Fine beams of high-velocity electrons passing through thin crystalline films produce diffraction patterns fundamentally similar to the X-ray patterns. Because of their very much smaller penetrating power, the electron beams are much better suited to the examination of surfaces. If X-rays were reflected from a very lightly oxidised copper surface, the pattern due to the underlying copper would nearly always be obtained. If the electron-diffraction photograph could be obtained at all, it would certainly give the pattern characteristic of the oxide. In addition, the actual exposure of the photographic plate to the beam need not be longer than a second or so. Electron-diffraction appears, therefore, to be a very suitable weapon of attack for all problems connected with surfaces. Apart from the cases of thin films already mentioned, and single crystal surfaces, it is generally true to say that good clear photographs, particularly of powders, are more difficult to obtain with electron beams than with X-rays. As so many of the specimens received for examination are in the form of powders, this certainly places a handicap on the method. No doubt, however, improvement of technique will take place in the near future, and the time may be looked forward to when electron-diffraction apparatus will be used side by side with and complementary to the more usual X-ray apparatus of industrial laboratories.

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Diesel-electric Propulsion Equipment of the "Lochnevis."

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Marine Dept. of The General Electric Co., Ltd.
and H. J. COATES,
Switchgear Dept., Witton Engineering Works.

ONE of the most interesting vessels built and launched during the year is the twin-screw Diesel-electric passenger ship "Lochnevis"—the latest addition to the well-known fleet of river and coasting vessels operated by David MacBrayne (1928), Ltd. of Glasgow. This vessel, which is shown in fig. 1, was constructed in the Leven Shipyard, Dumbarton, of William Denny & Brothers, Ltd., to the general design of Graham, Robb & Woolnough of Liverpool, under whose supervision the work has been carried out.

She has been built under the special survey of the British Corporation Register of Shipping and Aircraft and to the full requirements of the Board of Trade, for service mainly between Mallaig, Kyle and Skye.

The principal particulars of the "Lochnevis" are :

Length	175ft.
Breadth	31ft.
No. of passengers carried	700
Speed	15 knots

GENERAL ARRANGEMENT.

It will be seen from the general arrangement drawings, fig. 2, that the "Lochnevis" possesses an upper deck, a complete main deck and a partial lower deck with an open cargo-well forward provided with covers fitting flush with the deck. A shade deck and navigating bridge are built above the upper deck.

The hull is divided into eight transverse watertight bulkheads forming the fore peak, chain locker, a single cargo hold, crew accommodation, 3rd class refreshment room, engine room, 1st class smoking room, motor room and after peak. Portable stalls are provided on the main and upper decks forward for the carriage of cattle.

Generally, the accommodation for first class passengers is arranged aft, and that for third class passengers forward.

PROPULSION EQUIPMENT.

The propulsion equipment of the "Lochnevis" comprises two Diesel engines driving generators

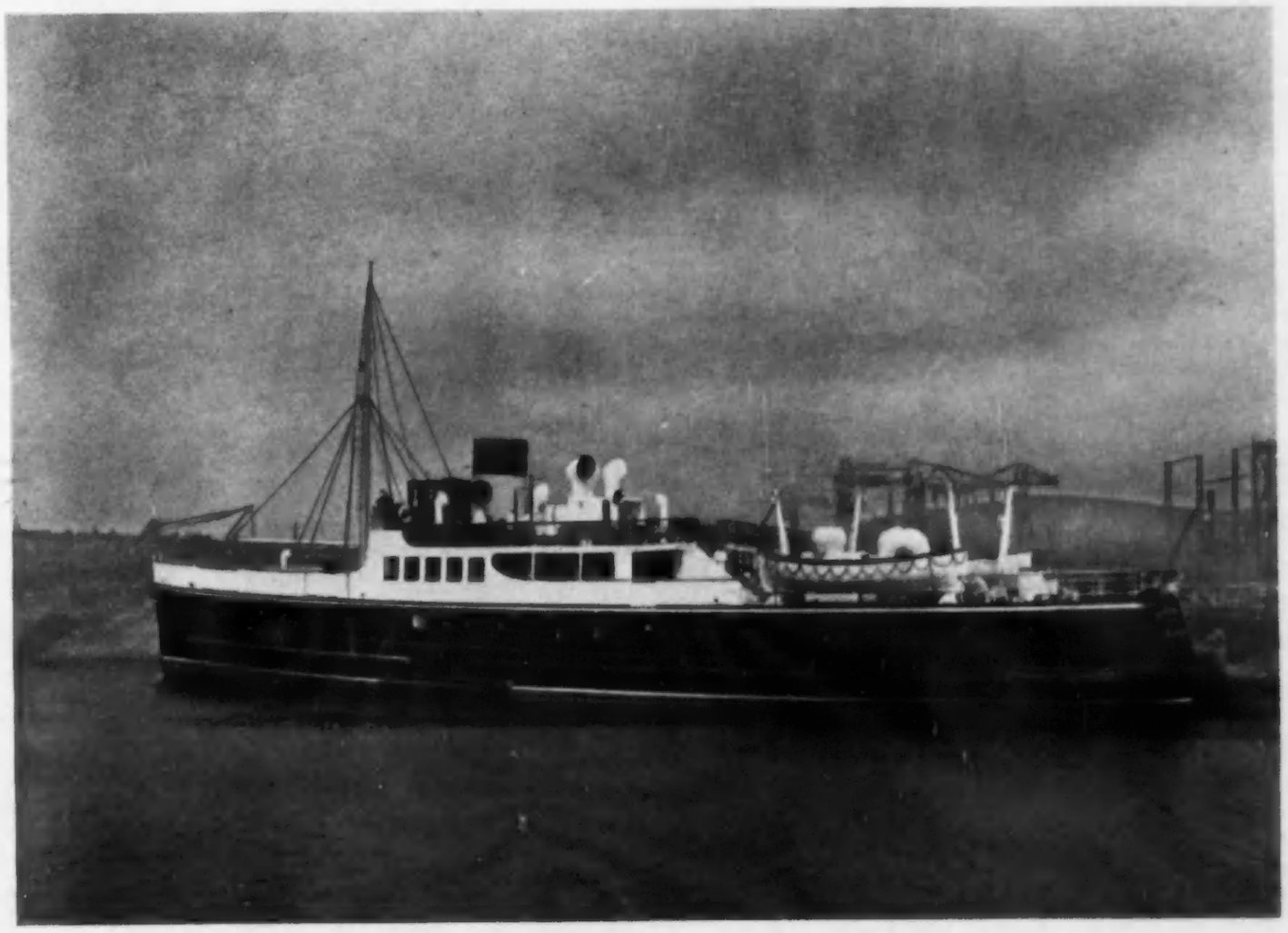
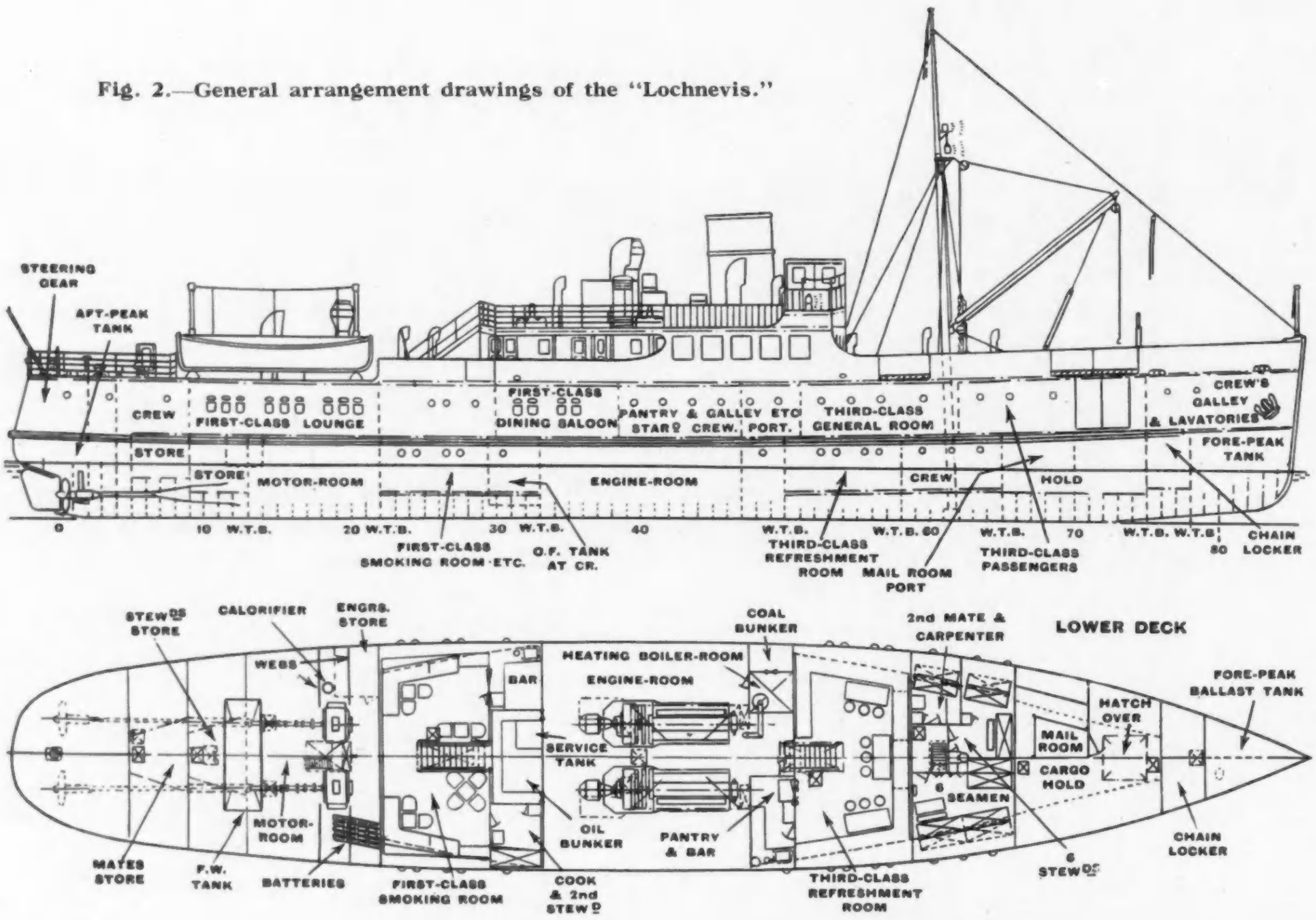


Fig. 1.—The Diesel-electric vessel "Lochnevis."

supplying current to two electric motors each coupled to a propeller through a line of shafting and thrust-block. Separate compartments house the generators and propulsion motors. The engine room is situated forward and contains the two

Fig. 2.—General arrangement drawings of the "Lochnevis."



main engines each direct coupled in tandem to a main and auxiliary generator. The main generators supply current to the propulsion motors only, while the auxiliary generators provide the electrical energy necessary for driving the engine room auxiliaries, field excitation current for the main motors and generators, and current for lighting, cooking and other services throughout the ship. This plant is controlled from main and auxiliary switchboards embodying a number of interesting features which it is proposed to describe later in this article.

The whole of this electrical equipment was manufactured and supplied by The General Electric Co., Ltd., the main Diesel engines being by Davey Paxman & Co. (Colchester), Limited.

MAIN ENGINES.

Each main engine (fig. 3) is rated to develop

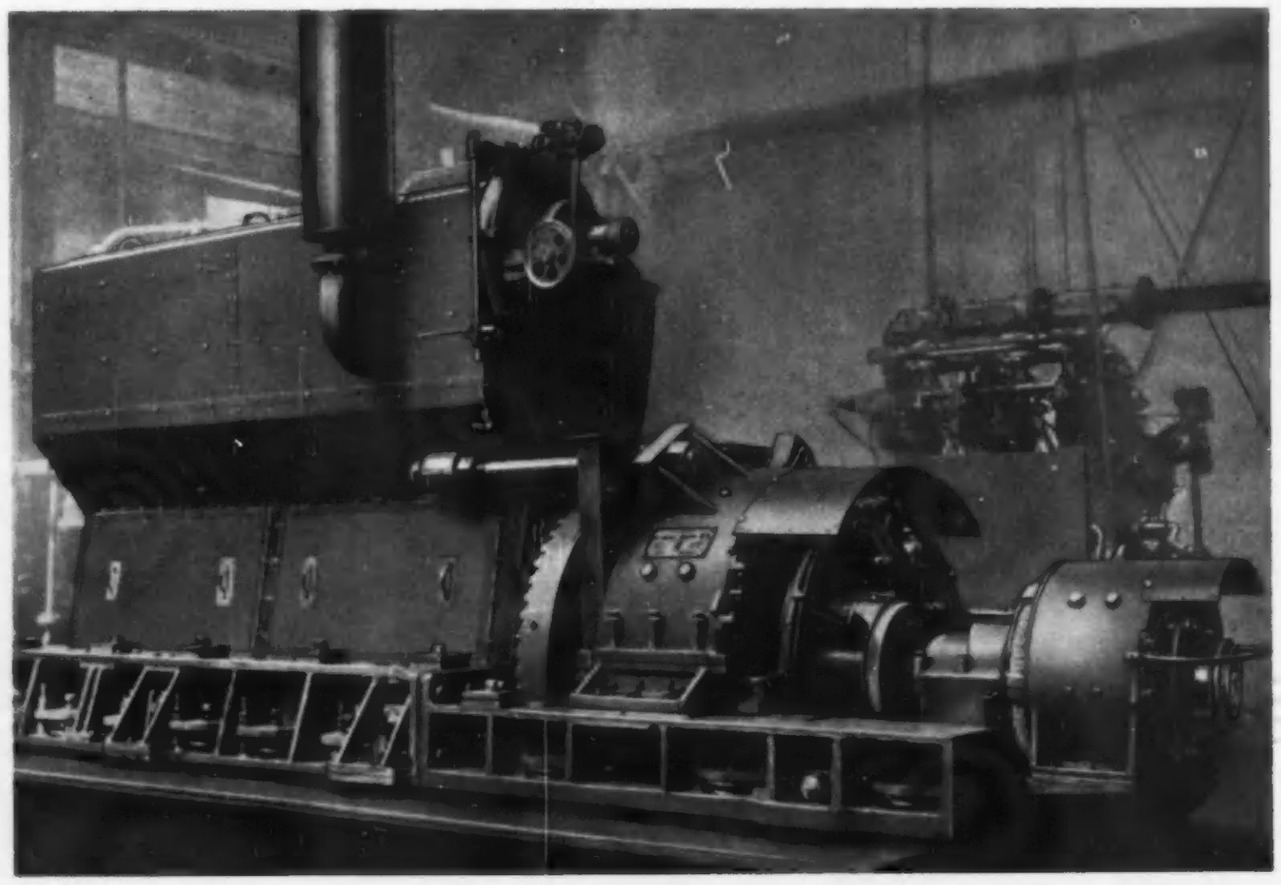


Fig. 3.—One of the main Diesel engines and generators on test prior to installation on board.

650 B.H.P. continuously at 500 r.p.m., and comprises a single acting 4-stroke cycle airless injection 6-cylinder unit having cylinders of 13in. bore by 16in. stroke. The design of the engines follows closely on the lines of the earlier Paxman heavy duty engines and embodies all their well-known features of design.

An interesting feature of the engine mounting is the adoption of an anti-vibration seating of a special type, consisting essentially of multiple adjustable spring supports with controls which are adjustable in any direction. The controls prevent excessive movement during pitching or rolling and also act as dampers to the spring movement. Spaced at

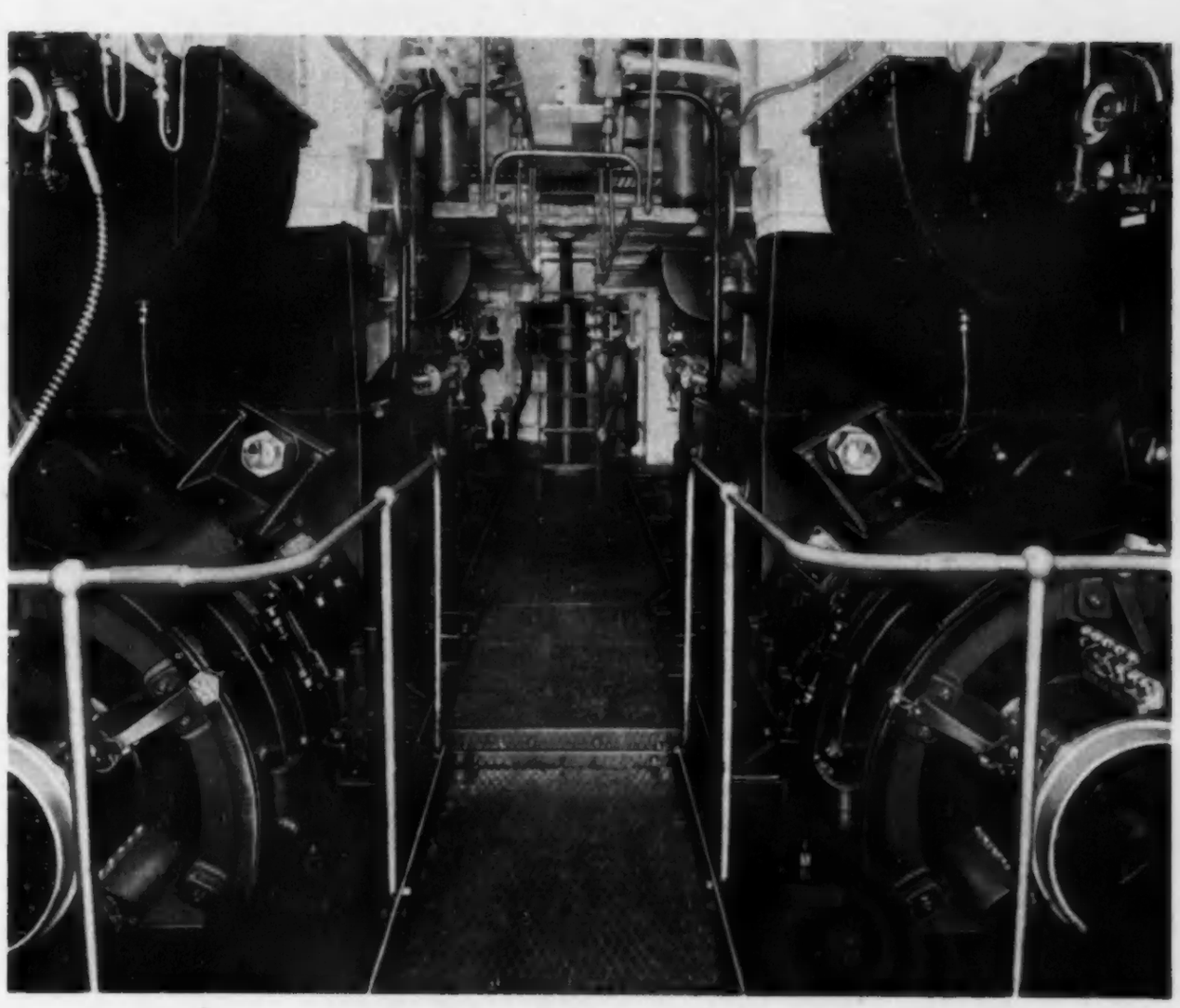


Fig. 4.—View down centre of engine room showing main engines and generators.

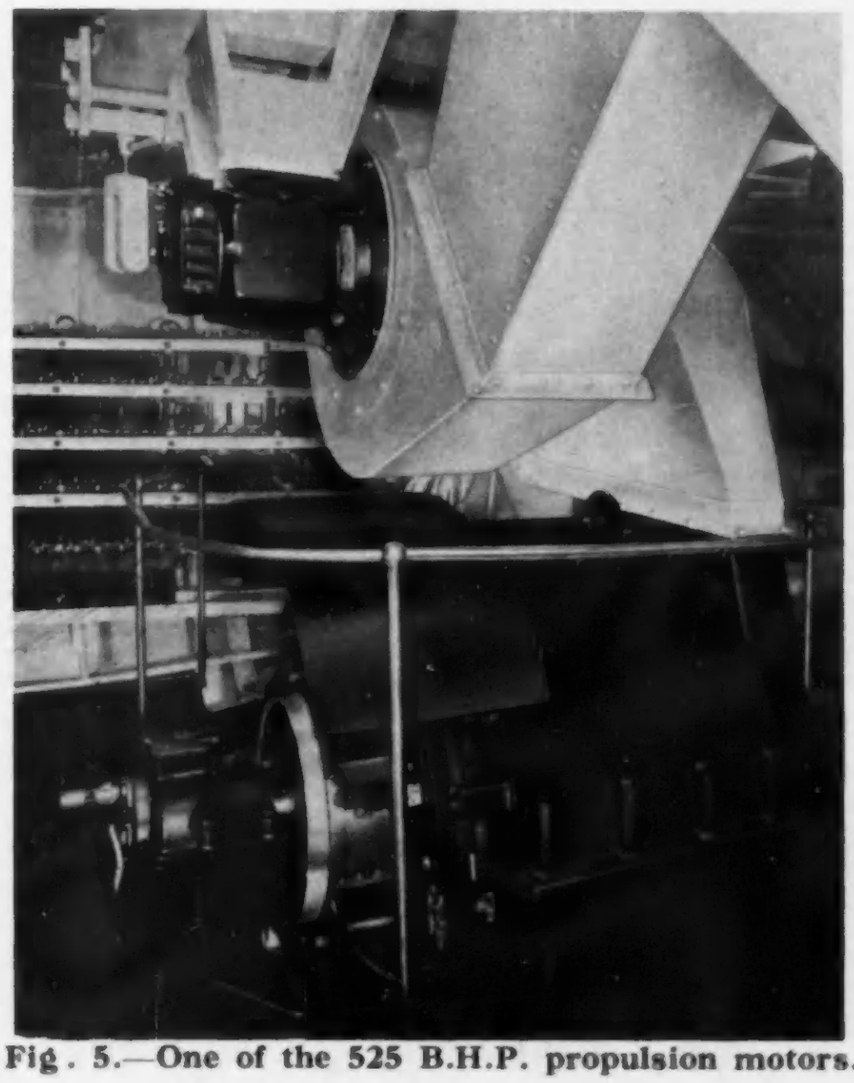


Fig. 5.—One of the 525 B.H.P. propulsion motors.

various intervals along the engine and generator bedplates (which are of special construction) are 18 coiled springs each provided with an internal damping pad. The weight of this bedplate is transferred to the springs by steel top plates which are adjustably connected to the bedplates by two tension bolts. In the centre of each top plate is an adjusting screw for the damping pad. As a result the bedplates are raised bodily approximately 2in. clear of their seating girders, the engine performing its work while resting on the 18 coiled springs already mentioned.

As each engine has 6 cylinders and rotates at 500 r.p.m., it will be appreciated that the frequency of the firing impulses is 1,500 per minute. The natural period of vibration of the spring mounted system has been designed to have a very low natural frequency—much below that of the engine—and as a result the transmission of vibrations of the control machinery to the seatings is greatly reduced.

In addition to these precautions taken to avoid engine vibration, the main crank-case has been treated with sprayed asbestos and the upper portion

of the engine provided with a lagged casing to reduce to a minimum any noise set up by the engine.

MAIN GENERATORS.

Coupled to each Diesel engine is a 425 kW 500 r.p.m. separately excited shunt wound generator (figs. 3 and 4), fitted with a light counter compound main series winding. Each generator is of the fabricated type and is bolted to a bedplate which is combined with the engine bedplate already described. Ventilation is effected by an internal fan, while lubrication is carried out by a disc and scraper, a method which has proved to be particularly suitable for marine work. The two generators are, in effect, connected in series, giving a voltage of 1,000 between the outer terminals and a voltage to earth of 500. Field excitation of the propulsion generators and the propulsion motors is provided by two overhung 230 volt auxiliary generators mechanically coupled directly to the propulsion generators.

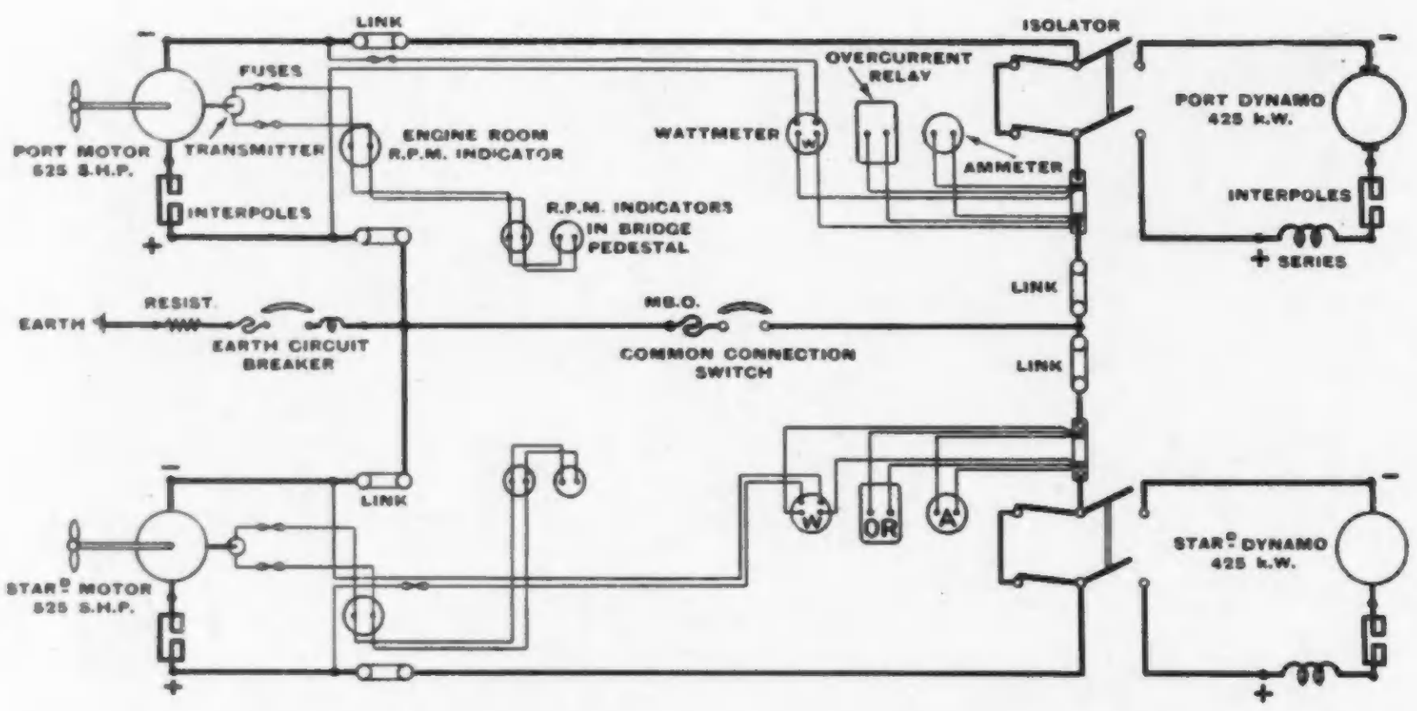


Fig. 6.—Diagram of connections of main current circuit.

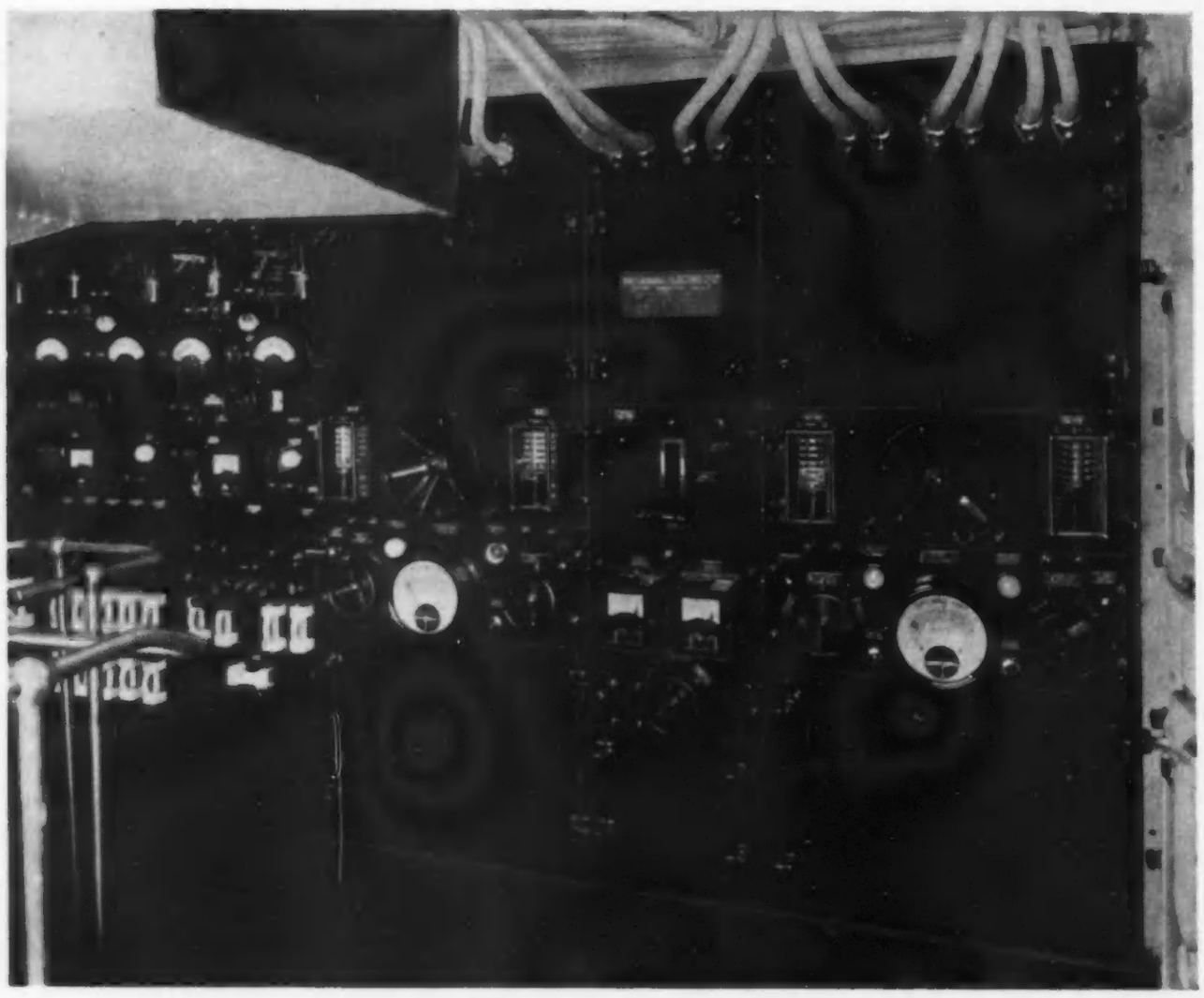


Fig. 7.—Main propulsion switchgear cubicle in engine room.

PROPULSION CABLES.

Pirelli-General marine type single core cable in sizes varying from 0.0045 to 0.4 sq. inch cross section is used to carry current from the generators to the motors and for control purposes. The control cable is insulated with varnished cambric, lead covered and armoured rubber sheathed and braided. The varnished cambric insulation has the great advantage of being non-hygroscopic so that it does not deteriorate if the sheath is damaged and it requires no special sealing ends. Thus it can be more easily accommodated in the restricted space available.

PROPULSION MOTORS.

Both propulsion motors are, as in the case of the generators, of fabricated construction and are rated at 525 B.H.P. at 400 r.p.m. Each motor (fig. 5) is provided with an external system of ventilation comprising a 17½in. fan inserted in a duct system which ensures a continuous circulation of fresh clean air.

The fan is driven by a 3 h.p. motor controlled by starters of the marine automatic timing type mounted in the engine room. As soon as the port and starboard excitation switches are closed these starters operate automatically.

The propulsion motors are directly coupled to the propeller shafts which they drive at a speed up to a maximum of 400 r.p.m. at a total shaft horse-power of 1,050. The propulsion motors and generators are capable of a continuous overload of 10 per cent.

Fig. 8.—Navigating bridge showing one of the two control pedestals providing direct control of the engines from the bridge.

MAIN SWITCHGEAR.

The satisfactory operation of any electrically propelled vessel depends largely on the design of the switchgear employed to carry out the various manœuvres required.

In a direct drive, twin screw vessel, failure of one engine obviously means that the corresponding propeller is out of service. Now in other electrically propelled twin screw vessels, failure of an engine results in a temporary failure of one propeller, followed by a shut down of the vessel itself pending a re-arrangement of the circuit connections. On the "Lochnevis," however, arrangements have been made so that, in the event of failure of an engine whilst the vessel is under propulsion, power for *both* propeller motors is automatically obtained from the remaining engine without any cessation of total power on either propeller.

The motors also continue to operate in whatever direction of rotation they had at the moment of engine failure, and they take up a maximum speed which absorbs the full output of the remaining engine.

The vessel therefore continues any particular movement in which it may be engaged at the time of the failure, though at slightly reduced speed. This

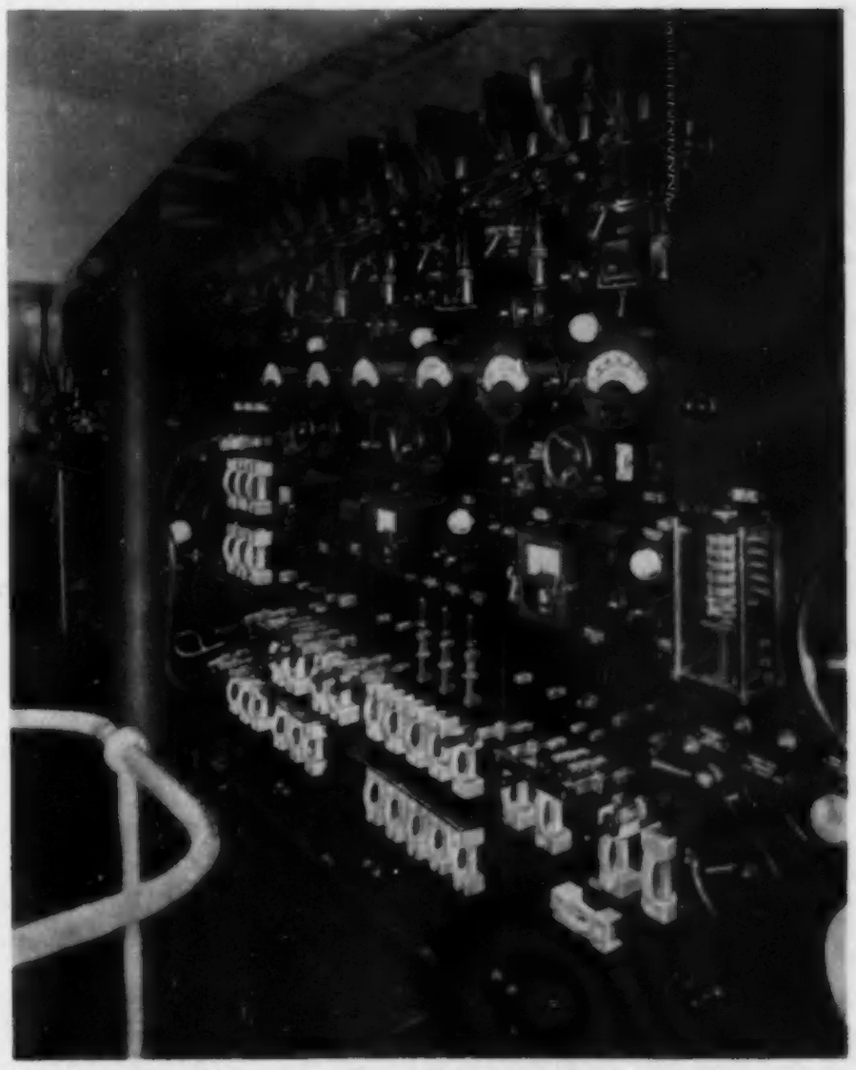


Fig. 9.—Auxiliary D.C. switchboard in engine room.

is a vital feature in the case of vessels navigating in narrow waters.

The method adopted for this purpose is patented

by the G.E.C. and consists of a 3 wire system of control as shown in fig. 6, with a circuit breaker in the common connection between the two generators and the two motors. Failure of an engine results in underspeed, and underspeed contacts are provided which trip out the field of the generators driven by the failing engine, and also open the breaker in the common connection.

For normal running, both propulsion generators with both propulsion motors are in use. Under these conditions of working the control of the port and starboard motors is quite independent as regards speed and direction of rotation. If desired, both motors may be operated from either of the two generators, in which case the speed of the two motors is always the same.

The main switchgear is mounted in a cubicle (fig. 7) comprising separate steel plate compartments fitted with hinged doors which can be removed to give access to the apparatus inside. This arrangement provides a dead front switchboard.

The switchgear controlling the main propulsion circuits is mounted at the top of the cubicles, while the various 230 volt field contactors, etc., occupy the lower portion of the cubicles. There are three main cubicles, one containing the equipment which controls the port side apparatus, one for the starboard side, and the centre cubicle for the apparatus on the common connection circuit. The arrangements are such that either the port or starboard cubicles may be rendered completely "dead," while the starboard or port equipment (as the case may be) still continues to function.

SYSTEM OF CONTROL.

Two methods of control are employed. In the first, the motors are controlled from the bridge (fig. 8) by means of controllers and pedestals situated on the navigating bridge. Two pedestals each with two levers are provided, one lever controlling the port and the other the starboard motor. Immediately below the pedestals are two watertight, multiple-contact controllers with resistances. Each controller is mechanically coupled by bevel drive to one lever on each of the two bridge pedestals, so that either controller can be operated from both ends of the bridge.

For the second method of control —by means of controllers and pedestals in the engine room, in response to the usual bridge-telegraph signals—two pedestals, each fitted with a single lever are provided. One pedestal controls the port and the other the starboard motor. Each pedestal is coupled by bevel drive to a multiple-contact field regulator switch with auxiliary contacts for generator and motor-field control, the regulating resistances being electrical duplicates of the bridge controllers. These switches with their resistances are mounted in a splash-proof casing, together with a second regulator, the switch of which is connected by bevel drive to a horizontal handwheel fixed on the top of a pedestal which is mounted adjacent to each control pedestal. This additional control is an auxiliary adjusting field regulator, and is used to compensate for differences between hot and cold field resistances and for fixing the maximum speed of the propellers for any particular service. The controllers referred to in both systems of control function as shunt regulators in the propulsion-generator field circuits, and enable the generator voltage to be varied from zero to 500 volts.

Should manoeuvring conditions cause an overload on the engine during the period of acceleration, an anti-stalling device functions, temporarily reducing the generator voltage. Immediately the overload disappears, the device is automatically reset, and the generator voltage rises to a value corresponding to the position of the control lever in use. A further feature of the control scheme provides for protection against the failure of a motor or of an engine. In the event of, say, the port motor failing when two engines are in use, a heavy overload current will flow. An overload relay on the port side of the

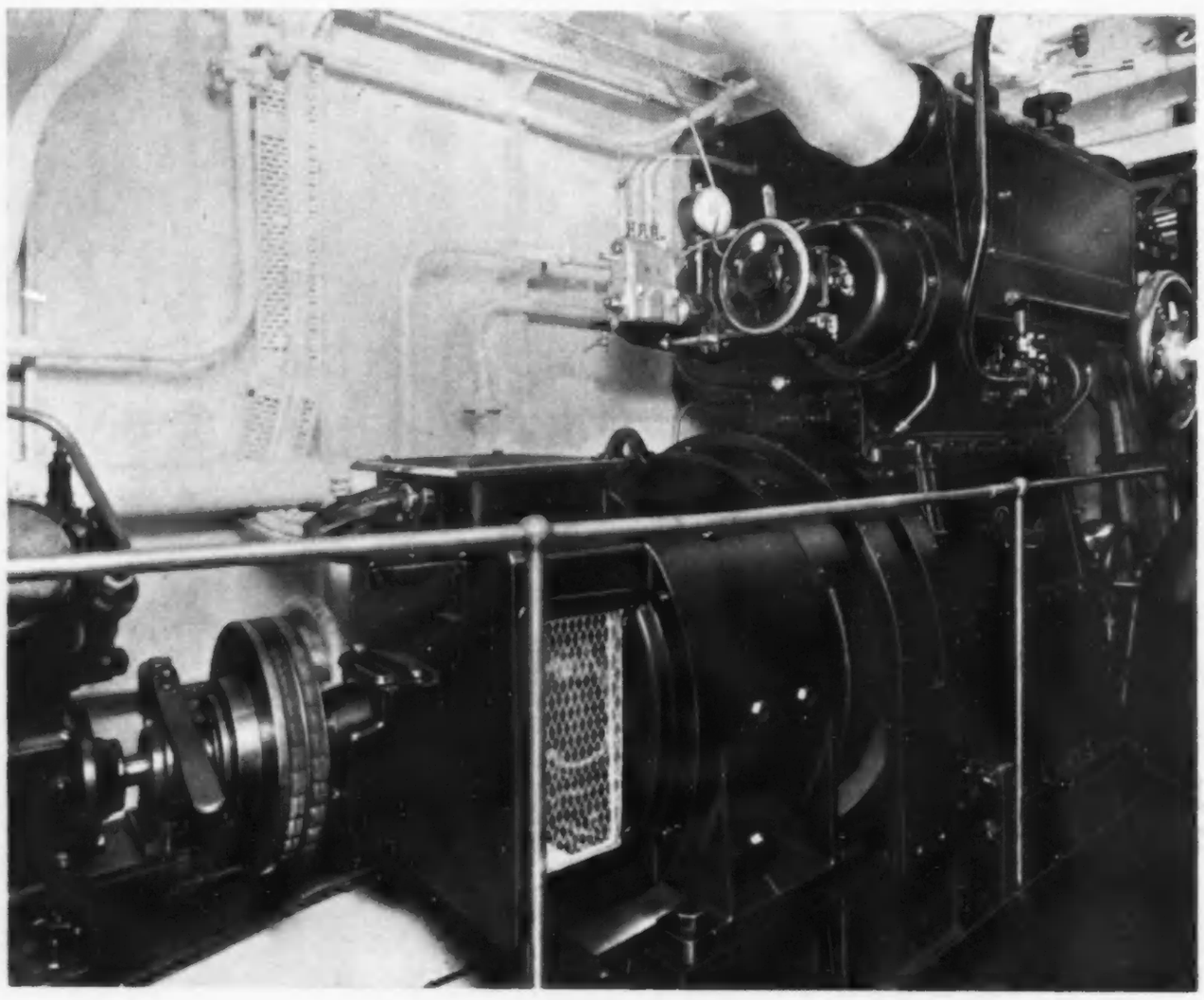


Fig. 10.—50 kW standby generator driven by 75 B.H.P. Diesel engine.

system then operates to open the port-motor field and the port-generator field, leaving the starboard motor running from the starboard generator. If only one generator is in use, however, the overload relays will remove all excitation.

In the event of failure of, say, the port engine when two engines are in use, the port engine will slow down, and an underspeed device would remove the excitation of the port generator and also open a breaker in the common connection of the port and starboard sides. Excitation would be retained, however, on the port-motor field. The current from the starboard generator would now be diverted from the common connection through the dead armature of the port generator and return through both motor armatures. The motor-field weakening

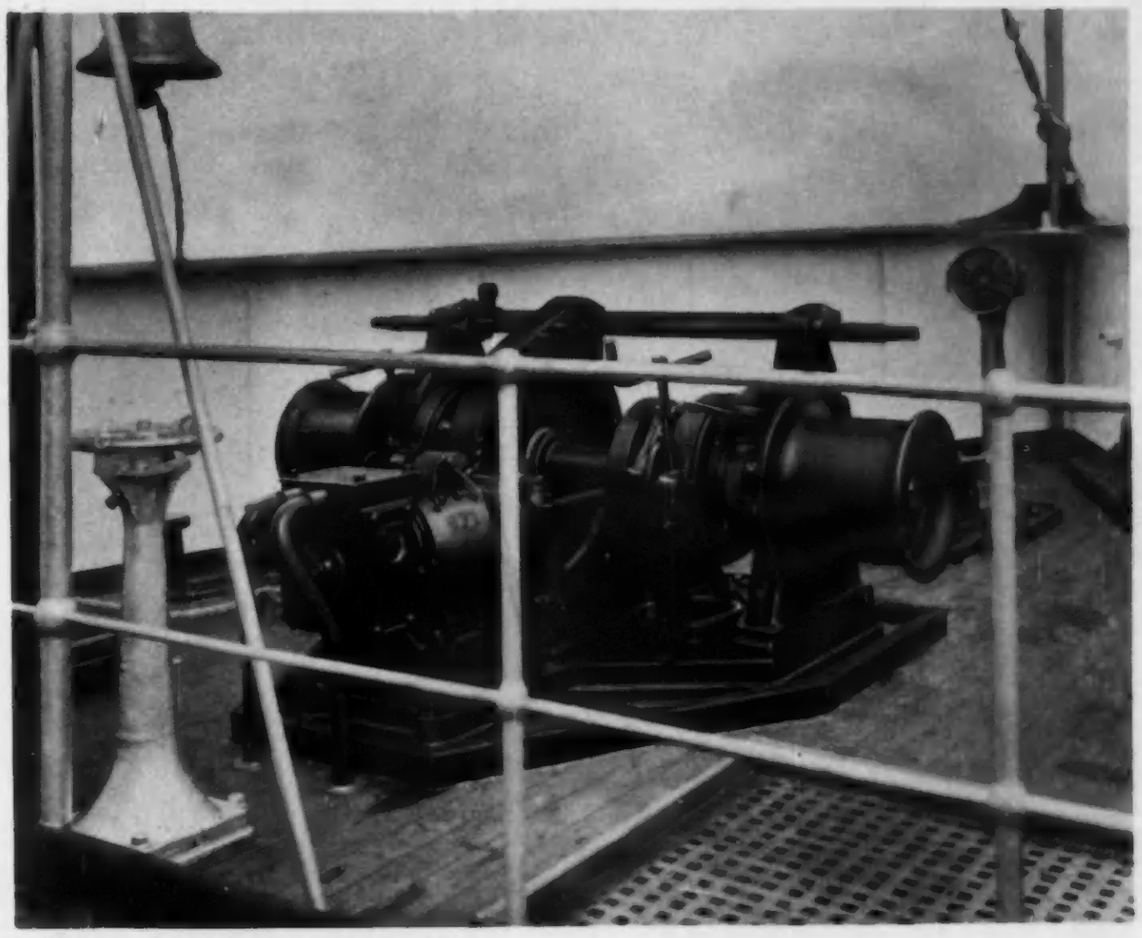


Fig. 12.—Anchor windlass driven by 10 h.p., 1,000 r.p.m. motor.

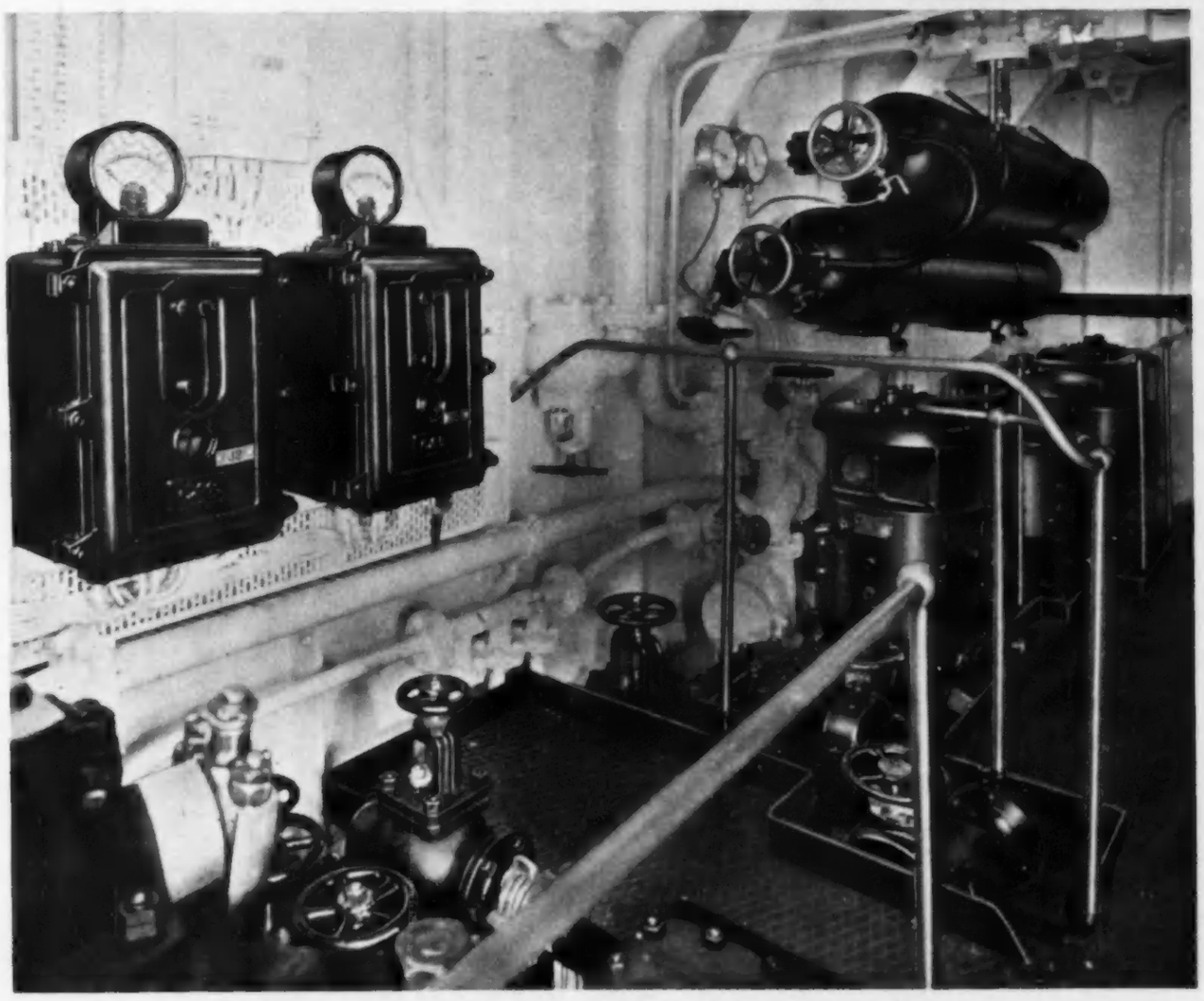


Fig. 11.—Two of the automatic timing starters controlling pump motors.

resistance would be automatically inserted and the bridge controls would also automatically revert to "one-engine" condition. This operation leaves the maximum possible power available on both screws, and the speed would automatically be adjusted on both motors to correspond to the starboard-control lever if the port engine fails. The direction of motion in each case corresponds to the lever co-related to the motor. Referring to fig. 6, it will be seen that, since reversing is carried out by altering the motor fields, the main-propulsion current always flows in the same direction, and as long as both screws are running at equal speeds no current flows in the mid-wire. If one motor runs at a lower speed than the other, then the difference in current in the port and starboard sides flows in the mid-wire.

A further point of interest is that when only one generator is in use to operate both motors, the port and starboard controllers are so interconnected with each other that either motor may be reversed relatively to the other by simply turning its control lever to the desired position, without having to move the control lever for the other motor. This operation removes excitation from the generator in service, reverses the field of the particular motor in question, and then restores the field of the generator. The one motor thus slows down and reverses; the other temporarily slows down, while both then rise in speed again to a value depending on the position of the control lever which corresponds to the generator in use at the time.

Transfer of control from bridge to engine room is arranged in such a manner that it is impossible to transfer control to either station unless both the controllers at that station are in the "stop" position, thus ensuring that no incorrect operations can be inadvertently performed.

AUXILIARY EQUIPMENT.

The auxiliary low tension switchboard (fig. 9) consists of four polished sindanyo panels on which is mounted the necessary gear controlling the incoming

supply from the two main and the standby auxiliary generators, and the outgoing feeders supplying power for the various auxiliary services.

A discriminating protective system is provided whereby if the load on the busbars temporarily exceeds the capacity of the generating plant, only the non-essential services are cut off leaving the essential services still in circuit. A triple pole circuit breaker is fitted for each generator, and knife switches and fuses for the feeder circuits, while two double pole knife switches with auxiliary contacts and locking devices are provided for isolating the port and starboard excitation circuits from the auxiliary supply busbars.

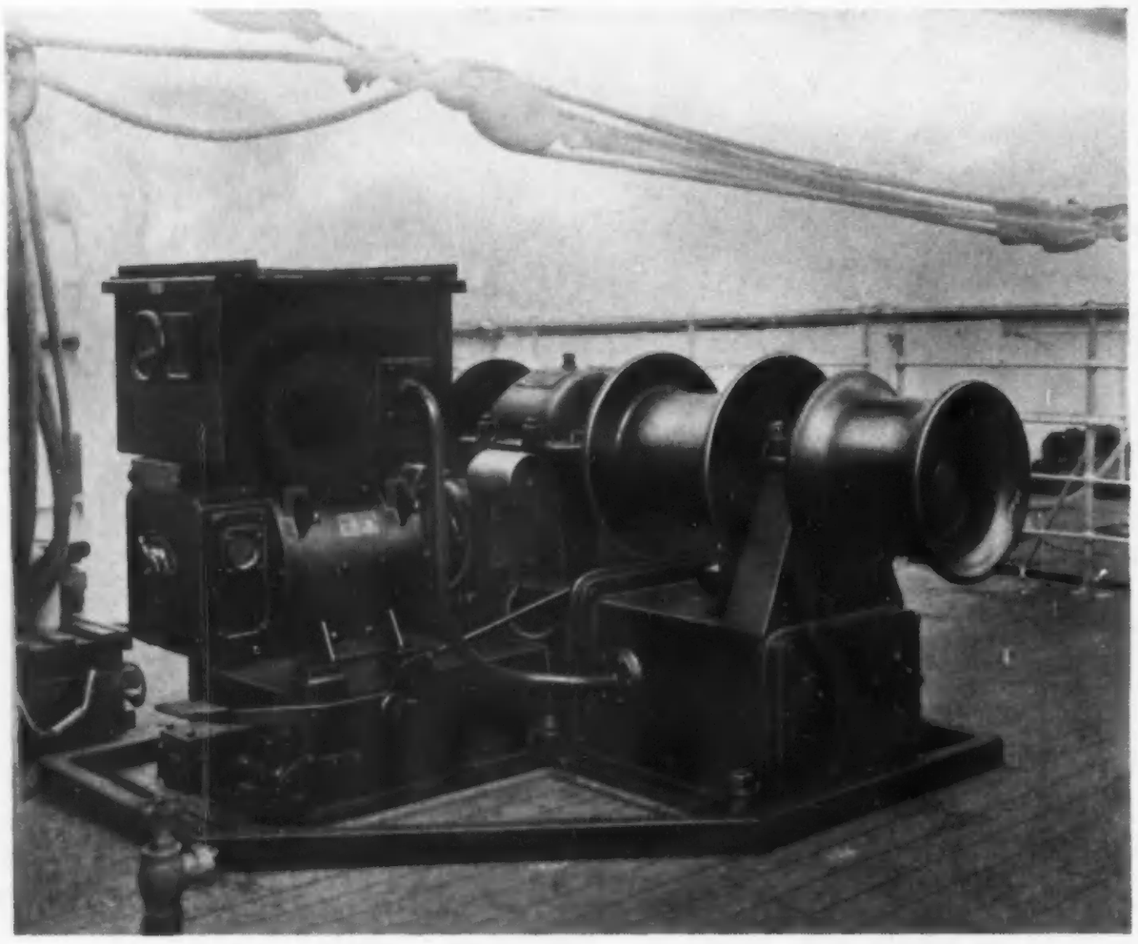


Fig. 13.—Cargo winch driven by 12½ h.p., 382 r.p.m. motor with drum controlled contactor starter.

The starboard side of the engine room is occupied principally by a standby generating set (fig. 10) and electrical switchgear. When at sea the auxiliary power in the vessel is supplied by the two main engine driven 50 kW auxiliary generators, which also serve as exciters to the main generators and motors. When in port, electric current is supplied by a 50 kW standby generating set, consisting of a Paxman three-cylinder, heavy-duty totally enclosed 75 B.H.P. Diesel engine running at 750 r.p.m., driving a directly-coupled 50 kW D.C. generator. A shaft extension drives a Reavell compressor through a clutch. The engine, generator and compressor are all mounted on a common bedplate.

The design of the auxiliary engine follows closely that of the main engines, with the exceptions that the valves in this case are horizontal and that there are two camshafts. The set is provided with its own independent starting-air bottle, as well as a pilot bottle for use in emergency. Unlike the main engines, the auxiliary set is bolted rigidly to its seatings.

The main engines are cooled by fresh water circulated in a closed system by a Drysdale vertical spindle centrifugal pump which circulates fresh water through the cylinder jackets and cooler. Two pumps are provided, one acting as a standby, and are located on the port side of the engine room. A Drysdale motor-driven salt water circulating pump serves the fresh water cooler, while a Dawson & Downie motor driven reciprocating general-service pump acts as a standby to the salt water pump.

A motor driven reciprocating bilge pump is situated at the after end on the port side, and immediately adjacent is a Reavell air compressor for charging the main engine air receivers. In all cases these auxiliary equipments are driven by Witton marine motors with push button controlled starters.

The deck auxiliaries are all electrically driven and include an anchor windlass (fig. 12), a 2-ton winch for operating a 5-ton derrick which serves the cargo hatchway and a warping capstan aft. The winch, fig. 13, is driven by a 12½ h.p. 220 volt motor running at 382 r.p.m. and has a drum controlled contactor starter mounted on the top. The capstan and windlass are driven by a 12 h.p. 600 r.p.m. motor and a 10 h.p. 1,000 r.p.m. motor respectively, the starters being mounted separately. The windlass winch and capstan are all of Clarke Chapman manufacture.

The steering gear has been manufactured by Thomas Reid & Sons (Paisley), Ltd., and is controlled from the bridge by a telemotor. The pinion engaging with the rudder quadrant is driven by a 4 h.p. 220 volt motor running at 700 r.p.m. This motor runs continuously in one direction only, reverse motion being obtained mechanically through a hunting reduction and reversing gear box. Hand steering gear is also provided aft.

SEA TRIALS.

Sea trials were carried out in the Clyde Estuary on the 29th June, when the performance of the vessel and her machinery proved in every way satisfactory. It is interesting to record that vibrographs were taken during the sea trials and clearly showed that no engine vibration was transmitted to the hull.

Three-core Oil-filled Cable.

By. R. E. HORLEY, M.I.E.E., A.M.A.I.E.E.,
Works Manager, Eastleigh Factory, Pirelli-General Cable Works, Ltd.

The successful operation in America of the single-core oil-filled cables for 132 kV designed and developed by Dr. Emanueli, Chief Engineer of the Pirelli Organization, led to the installation of similar cables in this country, most of them for 66,000 volts working pressure.

The manufacture, testing and installation of this single-core oil-filled cable have been fully described in the G.E.C. Journal, Vol. I, Nos. 2, 3 and 4. In the following article the author deals with the design, manufacture and installation of three-core oil-filled cable

IT is desirable, at the outset, to compare the advantages and disadvantages of single-core and three-core oil-filled cable. Single-core cables possess certain natural advantages. Longer lengths may be installed because they are lighter, the total volume of material in three single cables being less than that in a three-core cable for the same conductor section and working pressure. Single-core cables have no packing and contain less compound so that the increase in volume of compound due to the maximum temperature rise is not so large. On the other hand, with single-core cables, three joints are necessary against one combined three-phase joint; they cannot be armoured with the normal magnetic material because, with alternating current, in addition to the I^2R losses, caused by eddy currents, there is energy loss due to magnetic hysteresis. The total loss, indeed, may be as high as 100 per cent of the copper loss when the cables are armoured with galvanised steel wire. It is possible to reduce these losses by certain methods, but considerable additional complications are thereby introduced in the cable system.

With three-core cables, sheath currents and bonding problems are negligible. The laying of one three-core cable is cheaper than that of three single cores (except in the case where four single cables are considered to have the same standby value as two three-core cables) and they may be armoured with ordinary magnetic material such as steel wire or tape.

Before the introduction of three-core oil-filled cable, however, single-core cables had been employed as the only practicable type for 66 kV systems, for the reason that although the "T.L.S." and three-core "H" cables have proved successful for working pressures of the order of 33 kV, the thickness of insulation necessary for the higher voltage increases the overall diameter and consequently the weight per yard, so that it is only practicable to instal relatively short lengths.

This is not the case with oil-filled cable because the permissible maximum stress per m/m is considerably higher, resulting in the realization of a smaller

Fig. 1.—Laying 33 kV, three-core oil-filled cable on the chalk downs of Kent, September, 1934.

and lighter cable with a high factor of safety. Longer lengths may be handled and the number of straight through joints required is reduced. Comparative drawings of normal and three-core oil-filled cables are shewn in fig. 2.

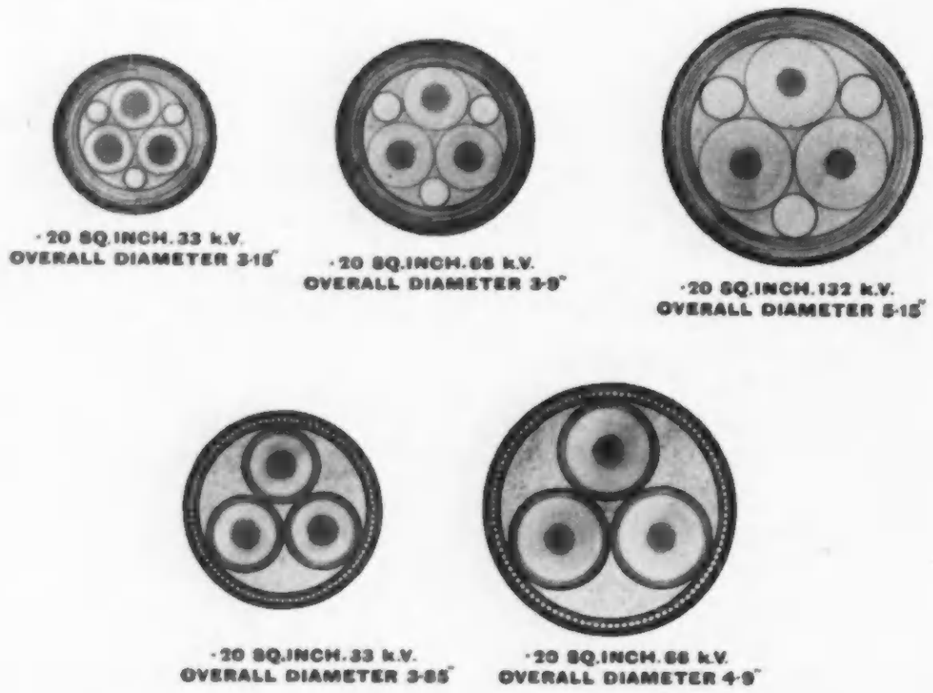


Fig. 2.—Comparative sizes of oil-filled cables (top row) and solid cables (bottom row).

MANUFACTURE OF THREE-CORE OIL-FILLED CABLE.

The construction of three-core oil-filled cable for 33 kV and 66 kV is similar to that of the single-core type, and the cable system is based upon the same principles, *i.e.*, external oil reservoirs are provided to maintain a positive pressure within the cable under all service conditions.

In three-core oil-filled cable, the conductors consist of regular strands of tinned copper wires which are insulated with graded paper in accordance with standard Pirelli practice. Each core is than lapped with a metal screening tape, so that it is electrically similar to a single-core cable. Three of these screened cores are laid up together by a laying-up machine which also lays into each of the three spaces formed between the cores, a metal oil duct composed of spiralled steel strip and sufficient paper packing to make the assembly circular. A cloth binding tape is then lapped around the cable. This tape has small copper wires woven into it which make contact with the screening on the cores, the metal oil ducts and the lead sheathing which is applied after the cable has been dried in vacuo.

The impregnation process is the same for all types of oil-filled cable and was fully outlined in the *G.E.C. Journal* (Vol. I, No. 2). It has been found unnecessary, however, to impregnate the cable twice, because the oil pressure within the cable can be maintained throughout the subsequent manufacturing processes by means of drum type pressure tanks.

After the impregnation has been completed and checked by means of the special tests previously described, the cable is passed to the brass tape armouring machine where it is first sent through a bath of preserving compound and lapped around with a cloth tape, after which an armouring of tinned steel tape is applied with a suitable gap. The steel tape is covered with a lapping of paper and a cloth tape is finally wound on over the paper. The object of the steel tape is to prevent the lead sheath from expanding when the pressure of oil rises during the working of the cable and the cloth tapes are put on to ensure that the steel does not cut into the lead when the cable is bent.

In this operation, as soon as the first end of the cable has been passed through the machine and arrived at the drum upon which it will be wound, it is connected to a drum pressure tank. The pressure tank connected to the other end of the cable is then removed. In this manner the cable is under oil pressure during the whole operation.

Fig. 3.—Three-core oil-filled cable in position for testing.

The cable is next taken to the lead press where it receives its second lead sheath. The excess volume of oil produced by expansion when the cable is being passed through the press is accommodated by means of the pressure tank. As soon as one end of the cable has been passed through the press and has arrived at the drum it is connected to a pressure tank incorporated in the drum. The other end is then disconnected from its pressure tank so that as in the previous operation, the cable is always under oil pressure. The cable is then served with compounded hessian tapes and finally compounded overall and whitewashed.

TESTING.

The cable is then taken to the electrical test bay. In order to carry out the electrical tests, the ends of the cable must of course be opened and fitted with sealing ends. The cable is maintained under a small head of oil by filling the sealing ends with oil and raising them a few feet above the top of the cable drum

Fig. 4.—Laying 33 kV three-core oil-filled cable in Kent, September, 1934.

Fig. 5.—View along the trench showing the cable in position.

as shown in fig. 3. The following electrical tests are taken :

The 66 kV cable is tested at a pressure of 106 kV to earth and the 33 kV cable at a pressure of 53 kV to earth for fifteen minutes in each case.

On both 33 kV and 66 kV cable, the dielectric power factor is measured at working voltage and at 1½ times and twice the working voltage, while the insulation resistance is taken at 500 volts D.C. Also D.C. tests for capacity and conductor resistance are made in the same manner as employed for ordinary cables.

When the electrical tests are completed, the sealing ends are removed, the cable ends cut off, and despatch caps fitted with conical unions are wiped on while the cable ends are still in the elevated position. Vacuum is then applied to the ends and impregnation is completed by the addition of dried and degasified oil. A drum pressure tank is next fitted to one end of the cable, the other end being disconnected from the impregnating plant and sealed with a blank nipple. The cable is then ready for despatch.

INSTALLATION.

All oil-filled cable installations, whether single-core or three-core, are divided into a number of sections each maintained full of oil under pressure from an external source. It is not practicable to feed more than a certain length of cable from one point because if a section were too long, not only would the hydrostatic pressure at the far end of the section be too great when the cable heats up under load, but also there would be too great a fall of pressure when the cable cools down, resulting

in the dielectric becoming unimpregnated at certain points and causing a breakdown of the cable.

It has been determined that the pressure must not fall below atmospheric at any point and this is the main consideration which determines the length of any section.

In order that the required hydrostatic conditions may be realised, it is necessary to be able to calculate the pressure at any point under all conditions of loading.

The fall of pressure when the cable is cooling depends upon two co-efficients :—

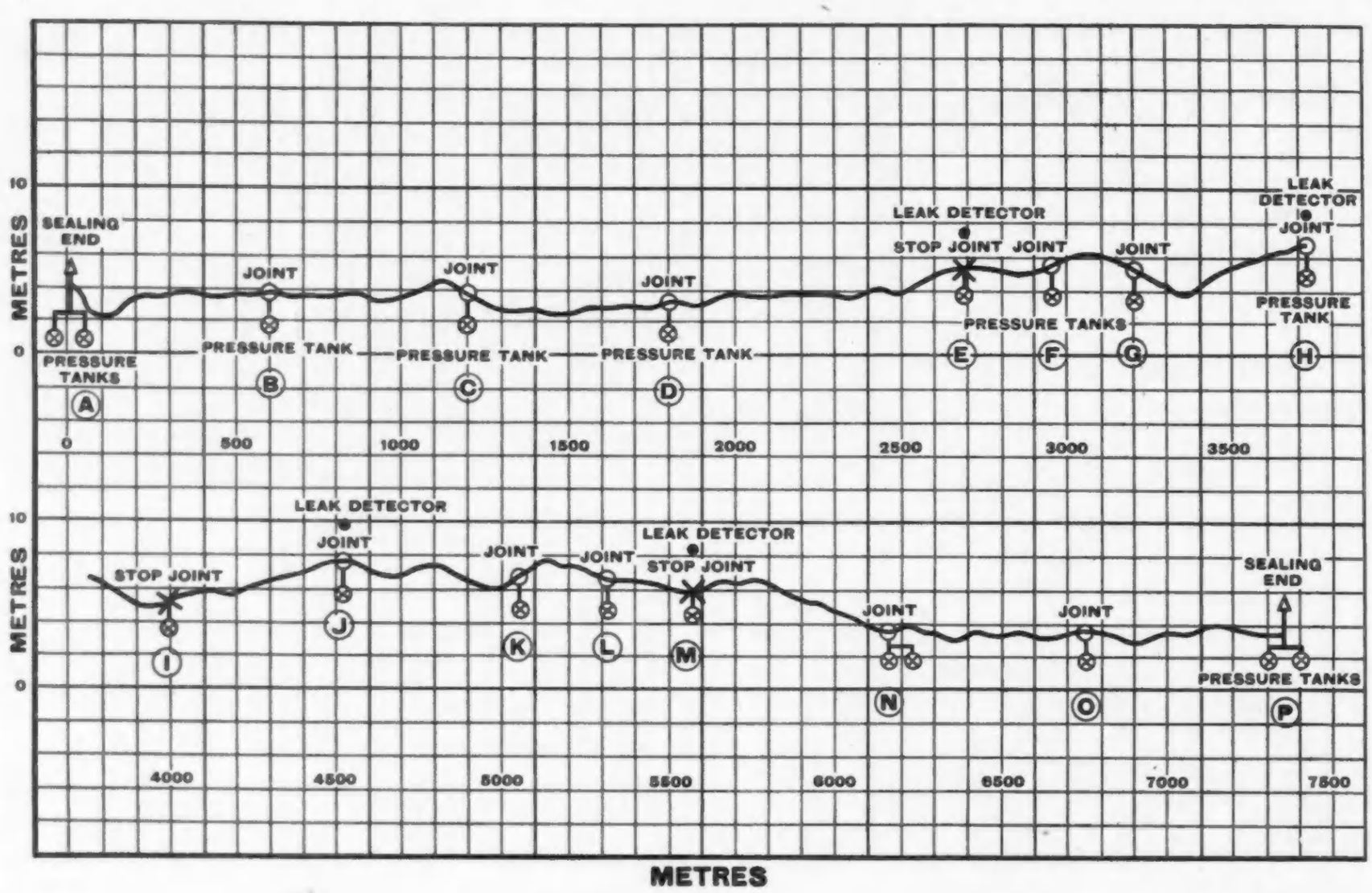


Fig. 6.—Profile of the 33 kV three-core oil-filled cable installed for the Central Electricity Board in Portsmouth.

a The rate at which oil is absorbed when the cable is cooling.

b The friction set up in the oil ducts opposing the flow of oil.

It is obvious however, that the profile of the route will have an important bearing on the pressure conditions within the cable when laid. In practice therefore, the profile of the route is plotted, and its effects at any point upon the pressure in the cable is taken into account in determining the section lengths.

The amount of oil which will be absorbed by the cable per unit length in unit time is arrived at by a consideration of the coefficient of expansion and specific heats of the various materials, and the heat dissipated under the particular conditions.

The rate at which oil is absorbed at a certain moment is proportional to the change in the amount of heat dissipated, *i.e.*, to the change in the losses in the cable.

This co-efficient (usually denoted by *a*) will have a maximum value when maximum load is switched off. Friction, which impedes the flow of oil through the duct in the cable, depends upon the size and geometrical form of the duct and the viscosity of the oil, the latter being a function of the temperature. Experiments have been carried out to obtain the co-efficient of friction of various shapes and sizes of oil ducts, using oils of different viscosities, so that having fixed the size and form of duct and knowing how the viscosity of the oil to be used varies with temperature, it is easy to calculate the duct friction co-efficient (usually denoted by *b*) for various conditions of loading.

The fall of pressure at any point is greatest when the product of *a* and *b* is a maximum. This maximum value of the product *ab* is employed in determining the pressure conditions in the line by means of a simple formula derived from the elementary principles of hydrostatics, thus :

Suppose a section of cable of length *l* fed at one end and terminated at the other by a stop joint or sealing end, is cooling down. The rate at which oil is being absorbed per unit length is *a* and the drop in pressure per unit length for unit rate of flow is *b*.

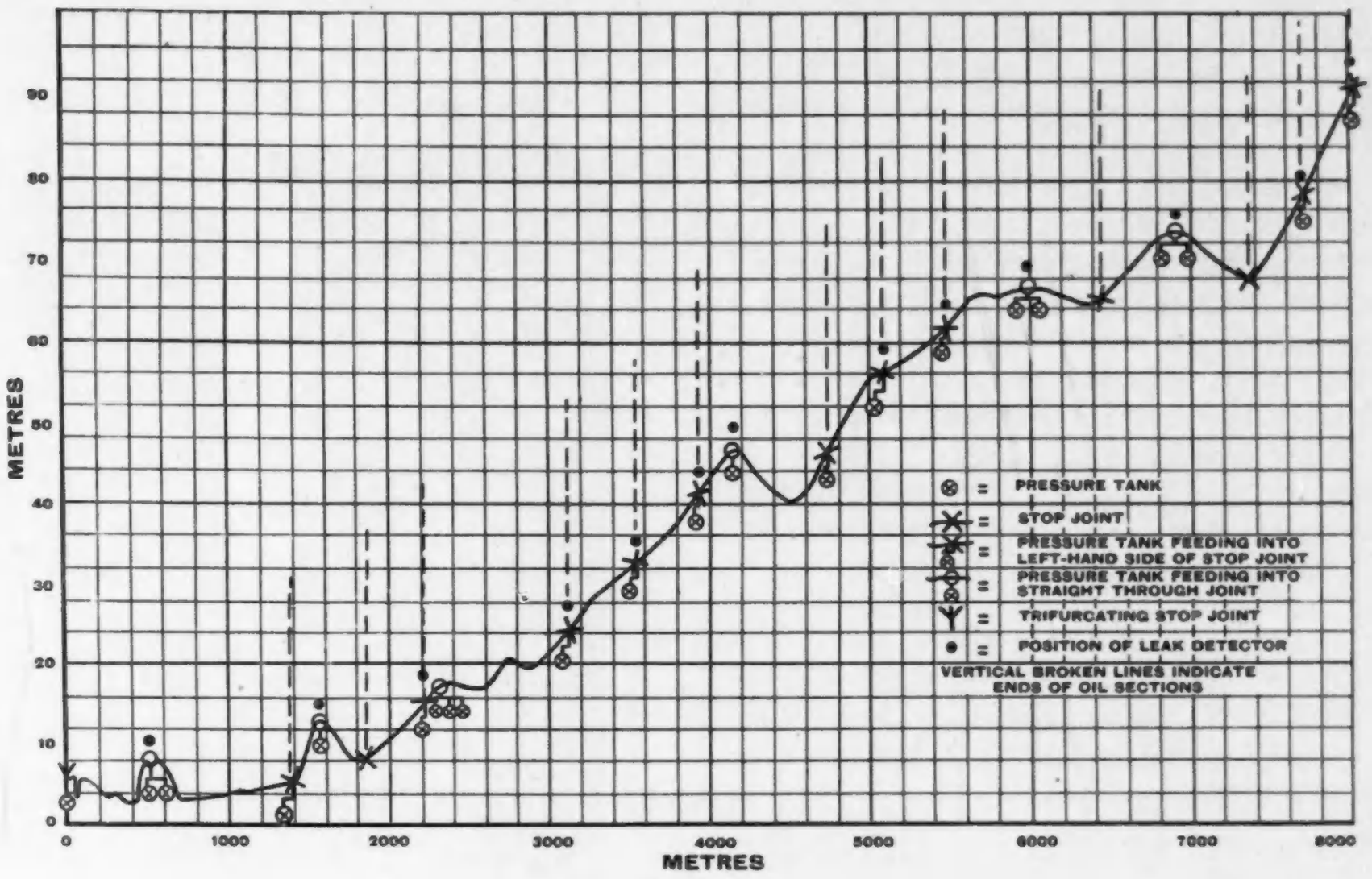
Consider a short length of cable δx, distant x from the feed point.

The rate at which oil is flowing through this portion of cable is obviously $a(l-x)$ and the resistance to flow is $b\delta x$.

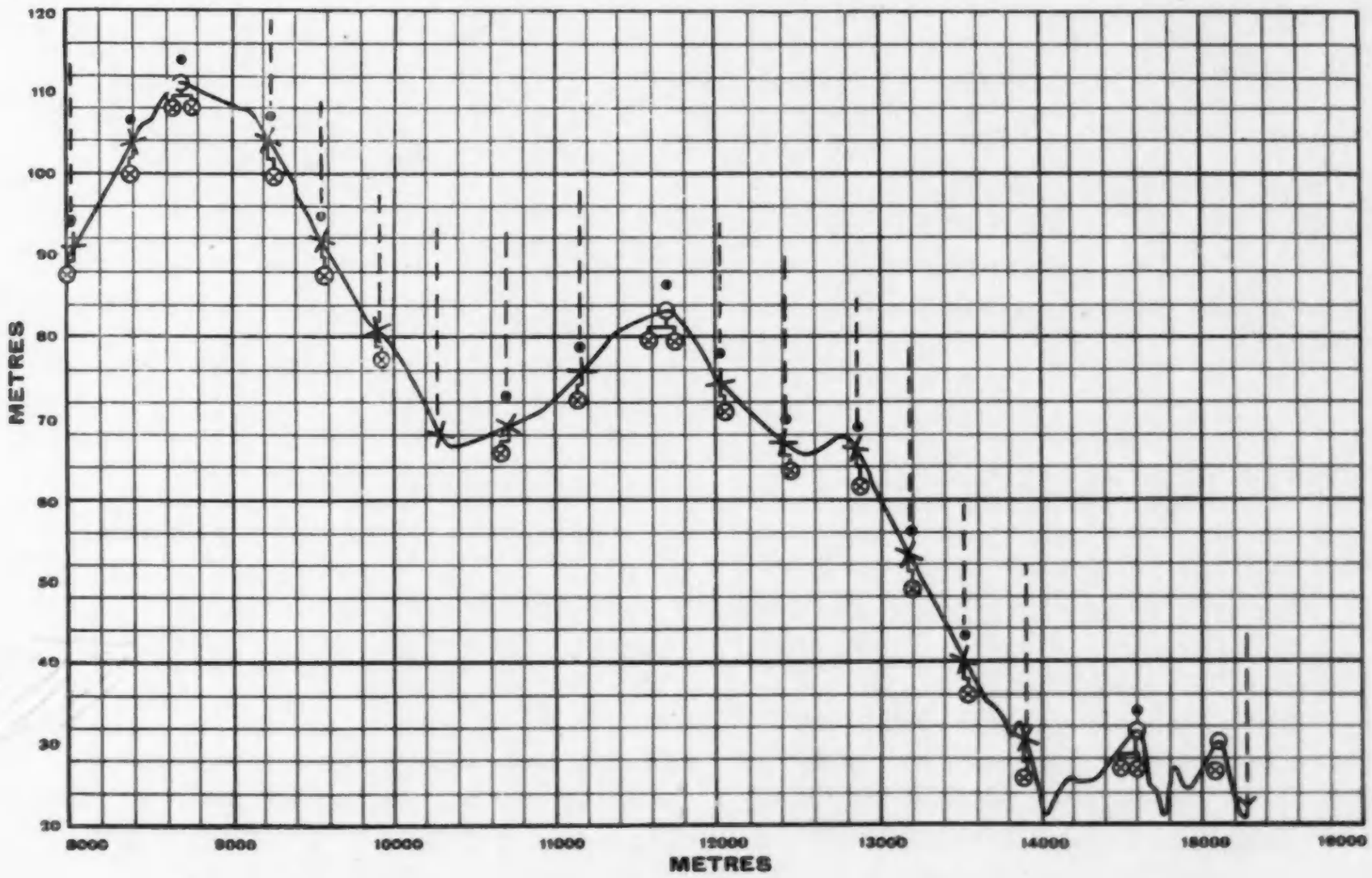
The drop in pressure in the length δx is therefore $a(l-x)\ b\delta x$, and the total drop of pressure from the feeding point to the point under consideration is—

$$\int_0^x ab\ (l-x)\ \delta x = ab\ (lx - \frac{x^2}{2})$$

At the stop joint position, $x = l$, and therefore,



(a)



(b)

Fig. 7.—(a) and (b).—Profile of the Bevans-Strood 33 kV, three-core, oil-filled cable. Total length, 9¼ miles.

the total drop in the section is $ab\ \frac{l^2}{2}$

Expressed in suitable units, the two formulæ given above are employed to investigate the oil

pressures under varying conditions in the design of every oil-filled cable system.

It has been found that Poiseuille's Law for the flow of a liquid in a circular tube can be applied to the flow of oil in a circular oil-filled cable duct, for the slow rates of flow which obtain in practice.

This law may be written:

$$p = \frac{8\,l\,q\,n}{\pi\,r^4}$$

where p is the difference in pressure between two points distant l apart, when liquid of viscosity n is flowing at a rate q in a tube of internal radius r.

In applying this formula to oil-filled cable calculations, r becomes the internal radius of the metallic spiral forming the oil duct.

By definition, co-efficient b is the drop in pressure per unit length divided by the rate of flow, *i.e.*,

$$b = \frac{p}{lq} = \frac{8\,n}{\pi\,r^4}$$

Usually, p is expressed in grams per sq. cm., n is in centipoises, and r in cm., so that the formula for b is

$$b = \frac{.0815\,n}{\pi\,r^4} \times 10^{-3}$$

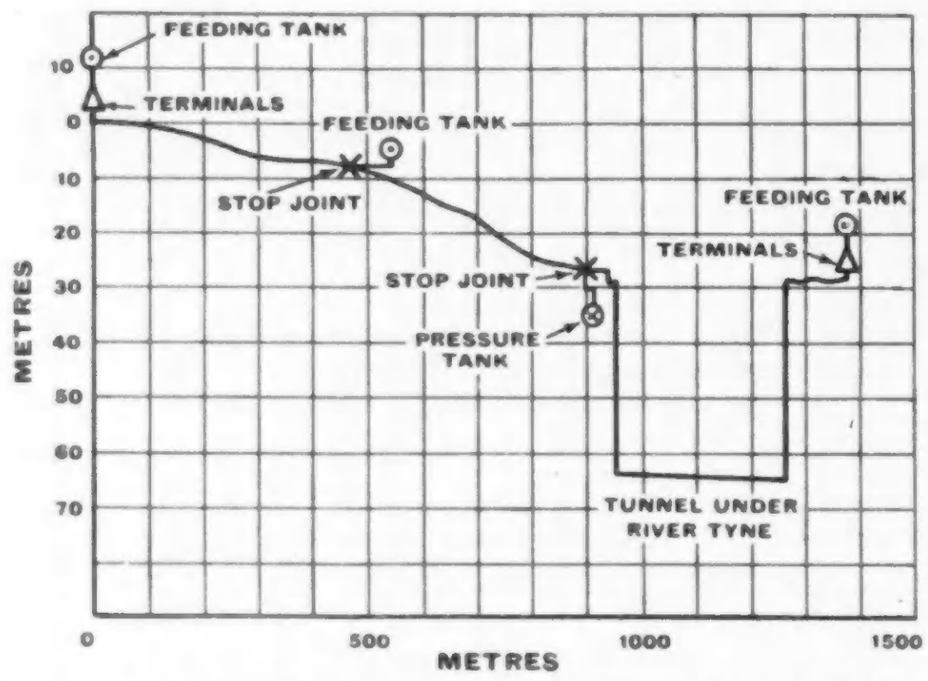


Fig. 8.—Profile of 66 kV, three-core, oil-filled cable installed between Hebburn and Carville.

The total volume under the lead sheath of a three-core cable is a little more than three times that of a single-core cable, and the maximum rate at which oil is absorbed or emitted is greater for the three-core type than for the single.

On the other hand, the three-core cable incorporates three oil ducts compared with one in the case of the single-core type, so that the friction co-efficient is less and the nett result is that the value of the product ab is approximately of the same order in both cases.

The pressure limits allowable are from slightly over atmospheric to 32 lbs. per sq. in. maximum and these are the same for both three-core and single-core oil-filled cables.

On a comparatively flat profile, a 33 kV three-core line could be conveniently divided into 440 yard sections, and each of these sections could be fed by one 88-litre pressure tank. It would be more convenient, however, to have very much longer

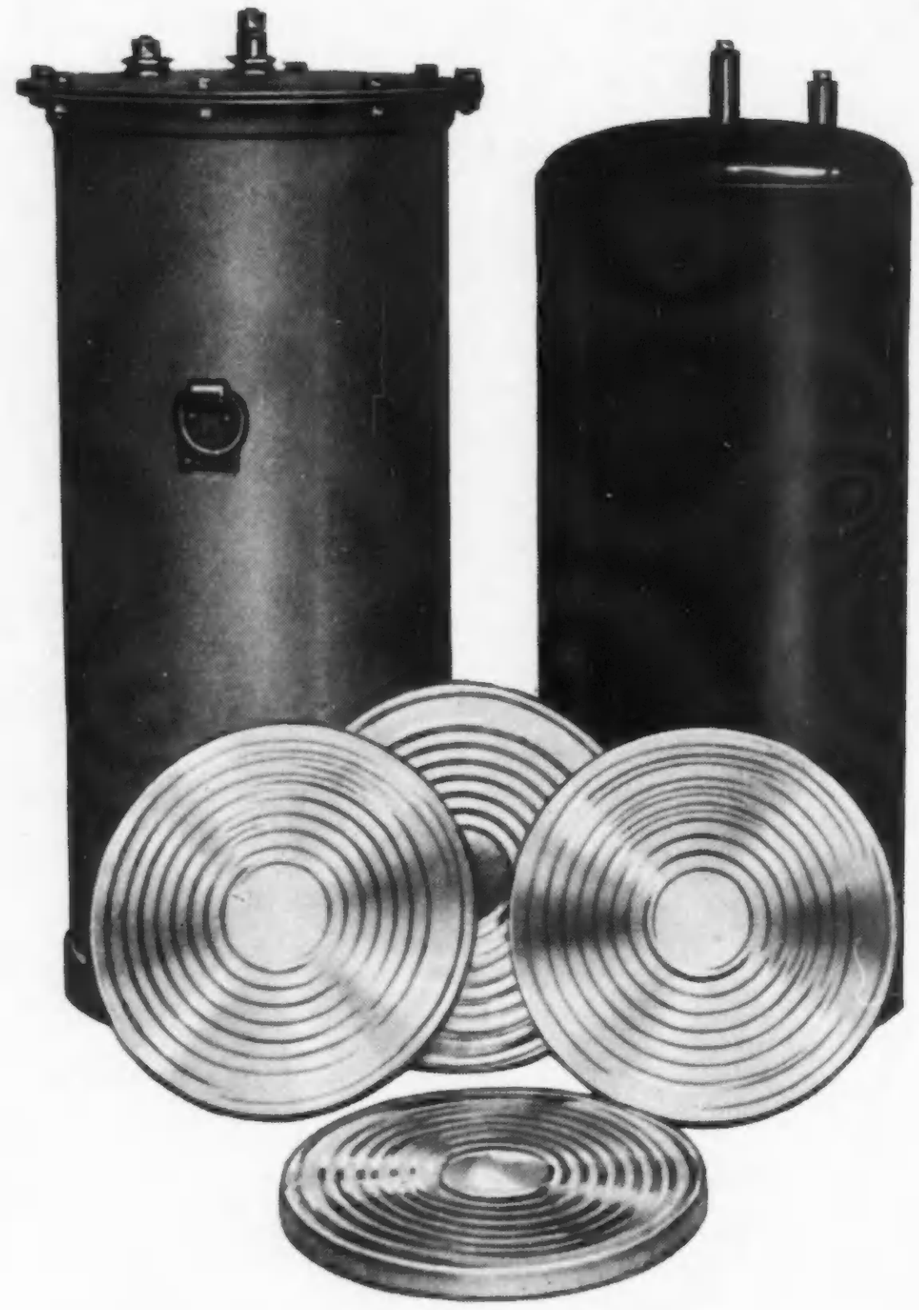


Fig. 9.—Pressure tank and components.

sections and a number of feeding points in order to maintain the pressure in the section within the necessary limits.

TYPICAL INSTALLATIONS.

An example of the last case is furnished by the 33 kV oil-filled cable installed for the Central Electricity Board in Portsmouth. This installation is approximately 4½ miles in length and is laid along an almost level profile (fig. 6). The cable is divided into four sections by means of three stop joints. There are sixteen feeding points and nineteen 88-litre pressure tanks. No gravity feed tanks are employed and the average length of cable fed by one tank is approximately 440 yards.

Another example is the Bevans-Strood three-core .15 sq. in. 33 kV oil-filled cable installation (fig. 7 (*a*) and (*b*). This line is approximately 9½ miles in length, the profile however, is hilly and the cable is divided into twenty-seven sections. The line has thirty-three feed points and forty-one 88-litre

pressure tanks. The average length of cable fed from each tank is approximately 410 yards.

Three-core oil-filled cable for 66 kV contains rather less than twice the volume of oil in 33 kV cable of the same conductor size, so that the tank capacity to feed a given length of cable is nearly twice as great for 66 kV as for 33 kV cable. This does not necessarily mean a greater number of tanks because larger tanks may be employed.

An example of a 66 kV three-core oil-filled cable installation of particular interest because of the exceptional profile of the route, is furnished by the double circuit installation under the River Tyne. These cables are .25 sq. in. and connect the Central Electricity Board switching station at Hebburn to the transformers at the Carville transforming station. The total route length between the two stations is approximately 1,570 yards. The length of cable installed in the tunnel is 447 yards and the vertical shafts leading to the tunnel are over 100 feet deep. A diagram of the profile and stop joint and feeding positions is shewn in fig. 8.

The dividing of the line into sections is effected by means of stop joints which electrically connect two sections of cable, but stop the oil communication between them. If required, oil can be fed to either section independently of the other. In the case of single-core oil-filled cable, the stop joint (unless special joints are introduced) is the only practicable position for feeding oil into a section, since the oil duct is in the centre of the conductor. With three-core oil-filled cable which has the oil ducts in the interstices between the cores, oil may be conveniently fed into any normal type of joint. Moreover, it is a comparatively simple matter to feed oil into the cable at any point by means of a plumbed pipe connection.

PRESSURE AND GRAVITY TANKS.

If the route were horizontal, pressure tanks equally spaced along the cable could be used without the introduction of any stop joints. Such a system however, would have the disadvantage that should a leak occur anywhere in the cable, the whole line would be affected instead of the oil leak being confined to a section.

Where the profile is suitable for the use of gravity tanks these can be used instead of pressure tanks or a combination of gravity and pressure tanks may be used. The design and manufacture of the gravity tanks were fully described in the *G.E.C. Journal*, Vol. 1, No. 2, but certain modifications of the pressure tank have since been effected. In the case of the pressure tank previously described, the elements were assembled between cast iron rings spaced by distance pieces and separated by long studs suspended from the cover and housed in a cast iron tank. In the new type, the elements are assembled in contact with one another and completely enclosed in welded steel tanks, a construction which results in a lighter and cheaper pressure tank. These new tanks also have the advantage that a greater saving in "dead" oil is effected due to elimination of the distance pieces. There is also a considerable reduction in the overall dimensions of the new type for equivalent capacity. Fig. 9 shows a pressure tank and its component parts.

The elements are composed of two corrugated tinned steel plate diaphragms which are reinforced around the periphery by means of a solid steel ring which is soldered in position. In order to ascertain the approximate life of these elements under working

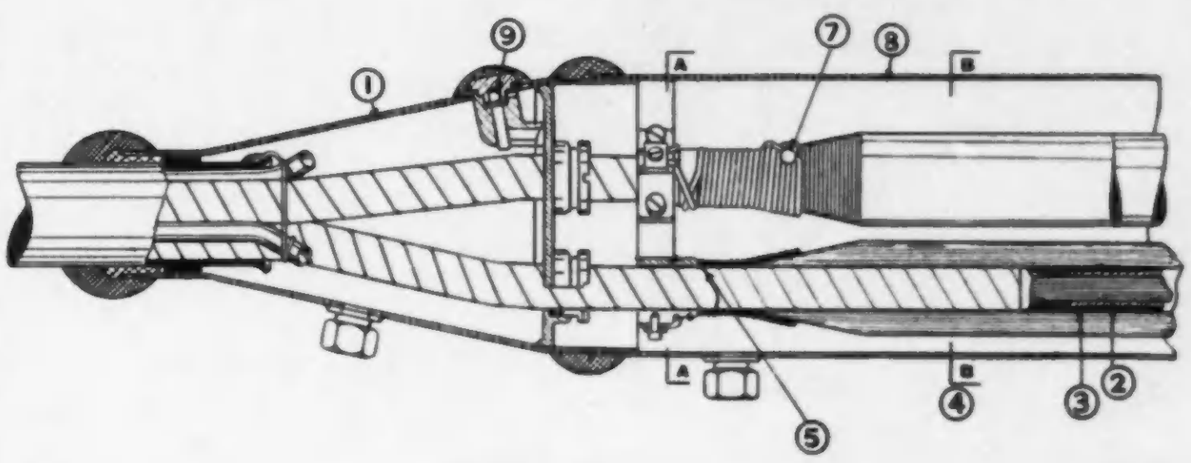


Fig. 10.—Straight through joint for three-core, oil-filled cable.

conditions, sample cells are subjected to cycles of high and low pressure tests in the following manner:

A number of cells are fitted into a tank which is then filled up with oil and sealed. The tank is connected through a rotary valve system to a compressed air line. Compressed air is admitted to the tank and the pressure is raised to 40 lbs. per sq. in. and maintained for half a minute. The air is then released to atmospheric pressure for a quarter of a minute, when the pressure is again raised to 40 lbs. per sq. in.

This cycle of operations is repeated automatically and the number of cycles required to produce failure of the element is recorded. It has been found that these pressure tank elements will not

fail under 20,000 cycles, representing a life of about 50 years working on a cable line.

To form a pressure tank, the correct number of elements to give the required capacity are placed inside a steel tank and the top steel cover is welded in position. The top of the tank is fitted with two connections of tubular construction. The first, which is provided for the initial filling of the tank, embodies a ball valve and a restrictor and the second is fitted with a ball valve only. The restrictor is fitted to prevent a rush of oil taking place when inspecting the oil in the tank after the cable has been installed. The pipe with the ball valve only, is for connection to the cable.

The completed inner tank is lagged with compounded hessian and then inserted into a galvanised steel outer protecting shell and the space between tank and shell is filled in with a special oil-resisting compound. A steel cover, which is provided with two packing glands for the outlets from the top of the inner tank, is then bolted in position.

During the past year a range of pressure tanks has been standardized giving five different capacities.

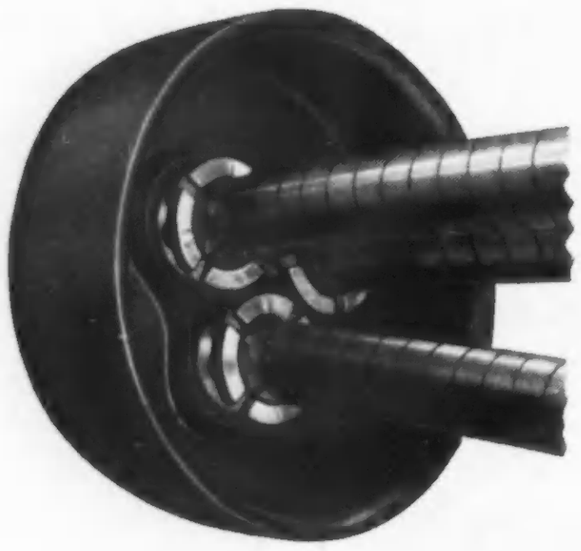


Fig. 11.—Oil restricting trifurcating end-piece.

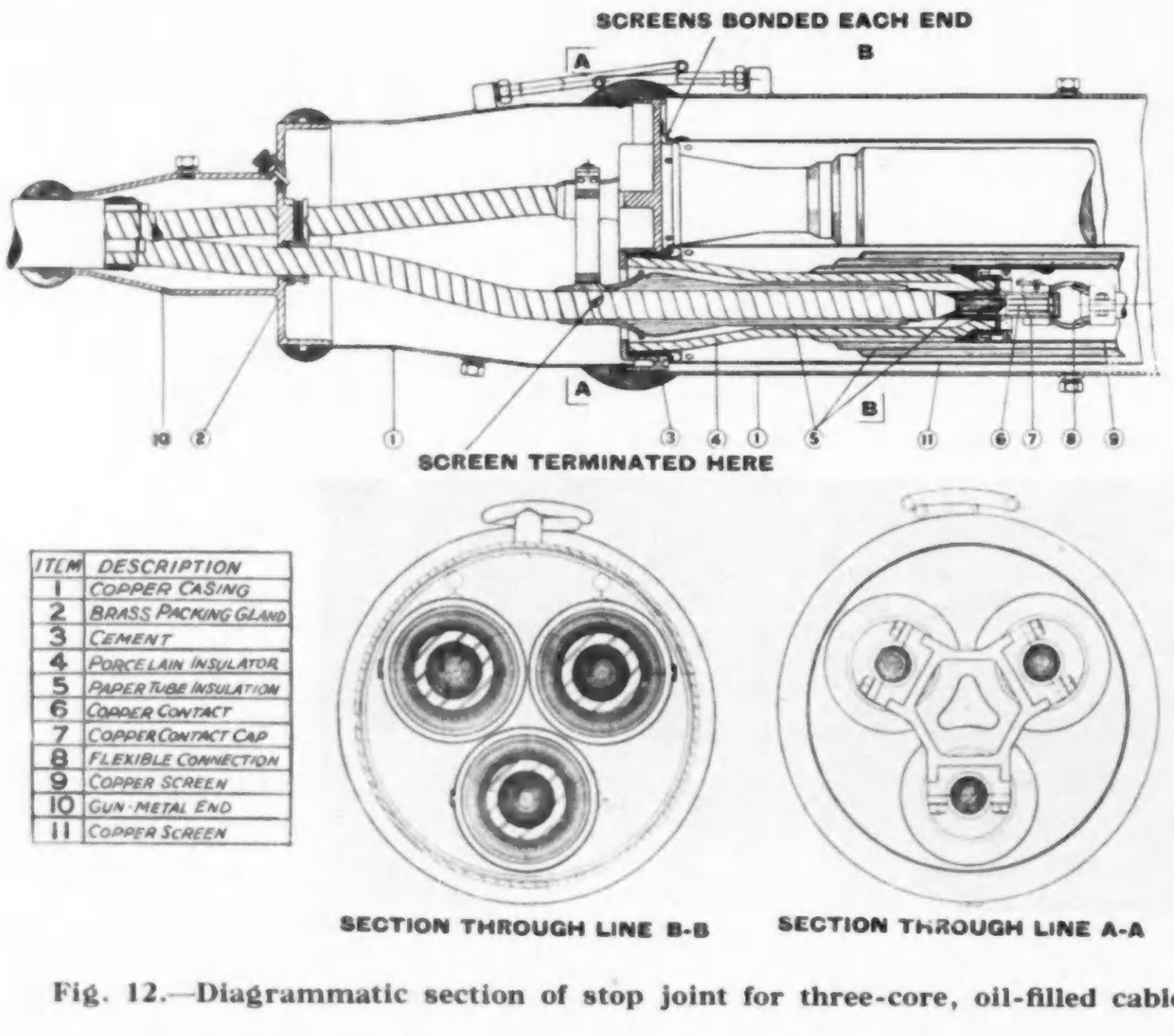


Fig. 12.—Diagrammatic section of stop joint for three-core, oil-filled cable.

STANDARD STRAIGHT-THROUGH JOINT.

The standard straight-through joint, fig. 10, for joining one length of three-core oil-filled cable to another is approximately 5ft. 8in. overall in the case of 66 kV cables, and 3ft. 6in. overall for 33 kV cables. The joint has special fittings (1) which restrict the flow of oil from the cable ducts until operations on the construction of the joint are completed. The conductors are connected by means of sweating type sockets (2) which are insulated with paper tapes (3) and Pirelli patent paper tubes (4). The brass tape screening (5) of the cable is secured by clamps (6) designed to form a spacer for the three cores and also a landing for the lead wire stress controls (7). The joint is enclosed in a cylindrical copper casing (8) which is wiped to the end casings (1).

After the joint is constructed, it is impregnated and continuity of the oil in cable and joint is established by means of a valve (9). The joint is finally lapped with hessian tape, painted over with hot black compound and enclosed in a concrete box filled with sand.

In constructing a three-core straight through oil-filled cable joint, the cables to be jointed are aligned and their ends are elevated three or four inches from the horizontal line in order to diminish the flow of oil and to avoid the trapping of air when the cables are cut. The outer lead is then cut back the necessary distance and before cutting the cables through, hot air blowers are put into operation so that the air in the immediate neighbourhood of the joint is warmed.

The cables having been cut through and the inner lead and oil ducts cut back to their respective positions, the three oil ducts are bonded together and to the lead sheath. Each cable is then fitted with the special end pieces, fig. 11, designed to restrict

the oil flow during the process of jointing. These end pieces are threaded over the cable cores and the glands are packed with cork rings.

After the fitting of these trifurcating joint ends, the cores are cut accurately to abut on the centre line of the joint. It will be remembered that in the case of single-core oil-filled cable where the conductors themselves form the oil duct, the ferrules are hydraulically pressed on to the conductors. In the case of the three-core oil-filled cable however, which has ordinary stranded conductors, sweating type ferrules are used and the sweating operations are similar to those employed for normal cables.

The insulation on either side of the ferrule is smoothly tapered off and the gaps formed between paper and ferrules are filled in with varnished silk tape up to the diameter of the ferrules. Varnished silk tape is then applied to bring the diameter up to that of the core when the joint is ready for the application of the main insulating tube, which consists of paper impregnated with cable oil. It is assembled centrally over the ferrule and tightened down.

The brass tape screening on the cores is terminated with suitable stress controls. The sleeve is then wiped in position and the joint is ready for impregnation.

STOP JOINT.

A three-core stop joint, fig. 12, measures approximately 8ft. 1in. overall in the case of 66 kV oil-filled cables and 5ft. 11in. overall for 33 kV cables. It consists essentially of an oil-filled cylindrical tank (1) containing three pairs of built-in porcelain insulators (4) with terminal caps, each pair being connected electrically by flexible couplings (8). The bases of the porcelain insulators are rigidly supported, three in each end of the tank. Each connected pair of caps is screened by means of a metal sheath (9) so as to obtain a good distribution of the electric field. The metal sheath is insulated by means of impregnated paper (5) each phase being screened overall from end to end by a cylindrical metal sheath (11). The tank portion of the stop joint, with insulators, caps and insulation, are prepared and impregnated in the factory and despatched to site hermetically sealed and connected to a small pressure tank, which must not be disconnected until plumbing and impregnation of end bells has been completed.

Special fittings (10) are employed on the ends of the cable and are so designed that the flow of oil can be restricted until further operations are completed. The cores of the cable are insulated in the field and provided with stress controls at the termination of the brass tape screening, fitted with specially designed spring contact plugs (6) and then inserted in the insulators so that their connectors engage with the contact plugs. Each end of the joint is next impregnated under vacuum and is connected to that side of the line at the higher pressure to allow for the changes of volume due to temperature variation. In this way the porcelain is always subjected to compression.

In constructing a stop joint, the cables are aligned alongside the stop joint with their ends overlapping approximately six inches. The outer lead is then cut back the necessary distance, the linen and steel tapes are removed and the inner lead is marked ready for cutting. After the cables are cut through, the inner lead is removed for the required distance and the oil ducts are cut back and

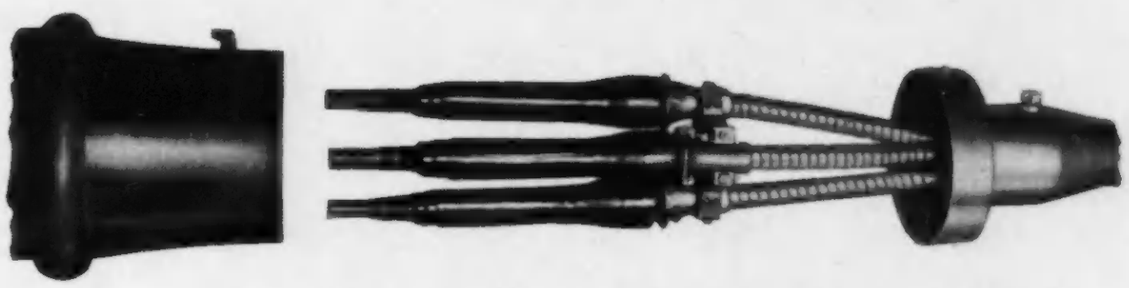


Fig. 13.—Prepared cable ends ready for insertion into stop joint.

Fig. 14.—Completed stop joint after impregnation.

bonded, one to another and to the lead sheath by means of copper wire. Special trifurcating joint ends are then fitted in the same manner as in the case of the three-core straight through joint in order to restrict the flow of oil during the jointing operations. The necessary amount of insulation is removed from each core and the sockets of the contact plugs are fitted to the conductors and sweated solid. The brass tape screening is removed for a given distance on each core and the cable insulation is reinforced by means of paper tubes, while stress control bells are fitted at the termination of the brass screening.

The prepared cable ends, fig. 13, are then inserted into the body of the joint and the joint is brought into alignment and carefully placed in position on one of the prepared cable ends. The other prepared end is withdrawn sufficiently to allow it to be inserted into the remaining end of the joint.

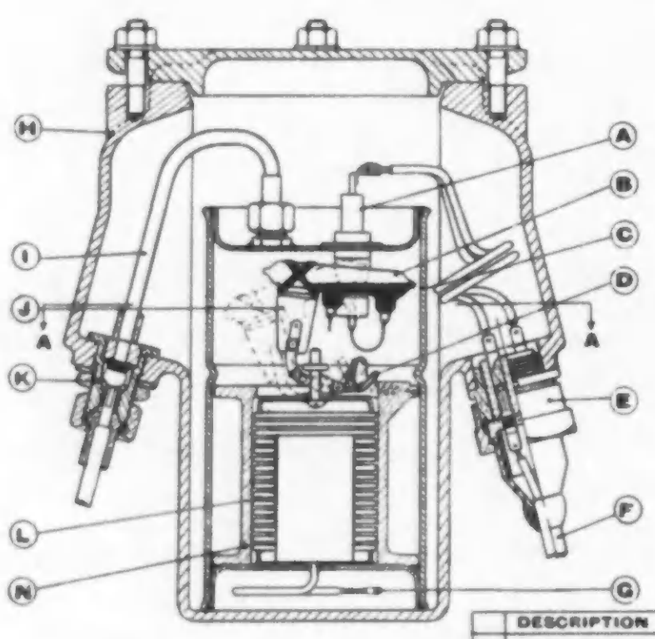
After it has been ascertained by measurement that the conductors are right home in their sockets, the sleeve is wiped in position and the stop joint is ready for impregnation.

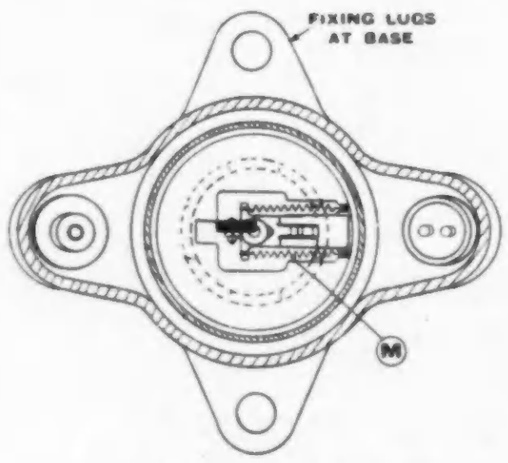
After impregnation, the joint is enclosed in a concrete box and is left for fourteen days for inspection to ensure that there are no oil leaks, after which the box is filled with sand and the concrete lid is placed in position. Fig. 14 shews a completed stop joint after impregnation.

DETECTION OF OIL LEAKAGE.

It is of the utmost importance that the pressure conditions within the cable do not become abnormal. If, for any reason, the cable is subjected to mechanical damage, resulting in an oil leak, the oil pressure in that section will fall in proportion to the rate at which oil is able to escape. It is therefore necessary to have a method of detecting such an eventuality.

One obvious method is a periodic inspection of the pressure tanks used for feeding the cable so that the pressure of the oil in the tanks compared with the load conditions of the line can be checked.





	DESCRIPTION	MATERIAL
A	INSULATOR	PORCELAIN
B	MERCURY SWITCH	
C	CASING	COPPER
D	SWITCH PIVOT ARM	G. METAL
E	PLUG & SOCKET	
F	CABLE	
G	REGULATING PIPE	COPPER

	DESCRIPTION	MATERIAL
H	EXTERNAL CASING	C. IRON
I	OIL PIPE	COPPER
J	SWITCH SUPPORT	FIBRE
K	OIL-INLET	BRASS
L	EXPANDING CYLINDER	ALLOY
M	ANCHOR SPRING	STEEL
N	SUPPORT	ALUMINIUM

Fig. 15.—Diagrammatic section of leak indicator for oil-filled cable.

This is only practicable, however, when the feeding devices of all the sections are installed in accessible positions. Where the feeding devices are buried or otherwise not easily accessible, the method is obviously impracticable. An apparatus which will automatically give warning should an oil leak occur at any point in the system has been evolved. It consists of a switch operated by oil pressure, which can be connected at any convenient joint—usually a joint near the highest point of the section—and an indicator alarm panel situated in the power station and so arranged that visible or audible warning is given in the event of the oil pressure in any section falling below a certain value.

The switching mechanism consists of a cylindrical collapsible chamber composed of a special metal, fig. 15. The chamber may be filled with air through the regulating pipe (G) and then sealed so that it can expand and contract in the direction of its axis when subjected to change of pressure. At the top

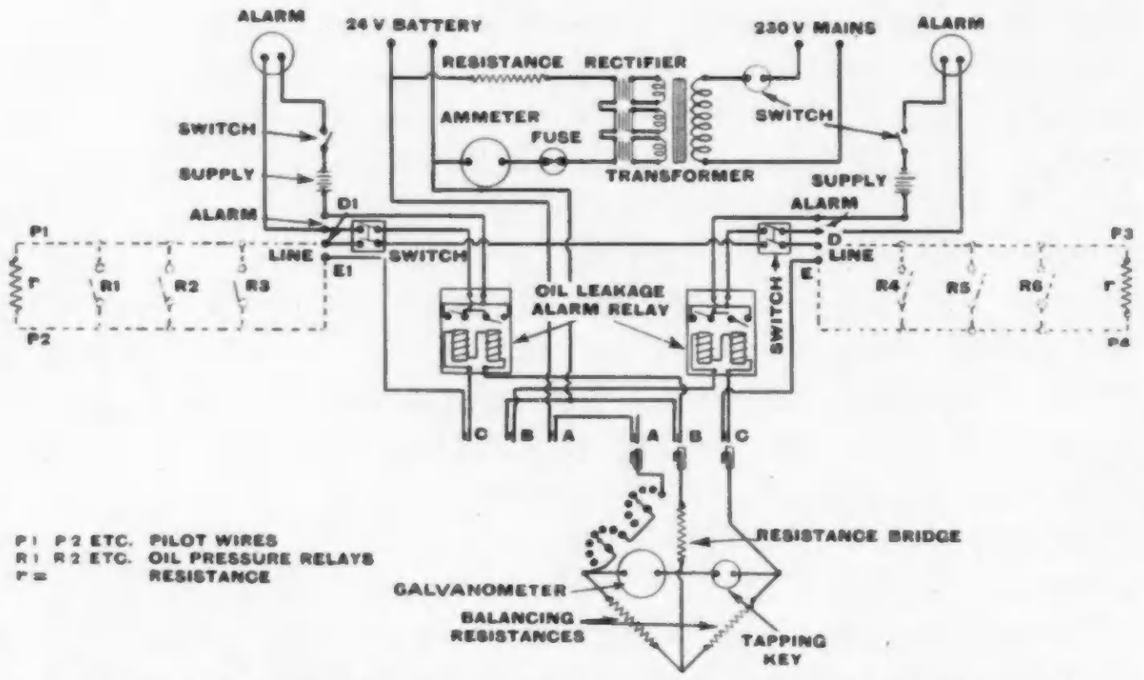


Fig. 16.—Circuit diagram of leak indicator for oil-filled cable.

of the cylinder and bearing upon it, a pivot arm (D) is arranged to pivot within definite limits about a bearing according to the movement of the collapsible cylinder. Attached to one end of the pivot arm is a mercury switch (B). This apparatus is enclosed in a copper casing (C) which is filled with oil. The oil pipe (I) is connected to the oil-filled cable joint through a ball valve (K) so that the oil pressure within the cable acts directly upon the collapsible cylinder inside the instrument.

The switch is connected across pilot wires which may be incorporated within the main cable or may be included with any pilot cable used for the electrical protection of the system. The pilot wires are brought to the indicator alarm panel where they are connected in series with a source of E.M.F. and two relays. The pilot wire circuit is completed through a resistance at the far end of the line as shewn diagramatically in fig. 16.

One of the relay coils which is connected in series with the other, is much more sensitive and the normal circulating current, about 6 mA, is sufficient to attract the armature of the more sensitive coil and thus keep the alarm switch in the "off" position. Another switch is connected in parallel with the first and is brought into the "on" position when a current two or three times the normal circulating current is present.

If the circulating current fails, due say to a breakage in a pilot wire, the switch working in

conjunction with the more sensitive coil will close, causing the alarm to operate. In the other case, if one of the section switches S1, S2, etc., closes, the resistance at the far end of the line is short circuited and the circulating current will increase, while the less sensitive coil will be energized sufficiently to bring its corresponding switch to the "on" position and operate the alarm.

If an accumulator is used as the source of relay current it must be kept fully charged : this is ensured by means of a trickle charger embodied in the panel, which may be arranged to charge continuously at about 0.1 amp., or alternatively at currents up to 1 amp. for shorter periods as required.

The alarm may be in the form of a lamp, Klaxon horn, or bell. The diagram shews the alarm energized from a separate battery but it can be connected to the main 24-volt accumulator if preferred.

If lamps are used as a means of giving the alarm, however, the supply mains can be conveniently utilized for this purpose.

Besides the relays, relay switches, alarm, accumulator and pilot line connections, the panel, fig. 17, is fitted with a Wheatstone bridge, galvanometer and an ammeter. When the panel has been erected on site, the bridge readings to each oil switch will be measured and tabulated.

It follows that if the alarm should operate while the cable is in service, all that is necessary is to switch off the alarm, insert the plugs in their corresponding jacks and balance the bridge, thus noting from the table the switch which has closed.

In an emergency, if the oil pressure in a section falls below a prescribed limit, it is possible to keep the cable in service while measures are being taken to restore the pressure.

In conclusion it is interesting to note that there are approximately 600 miles of single and three-core oil-filled cables for working pressures of from 33kV to 220 kV in satisfactory operation in various parts of the world.

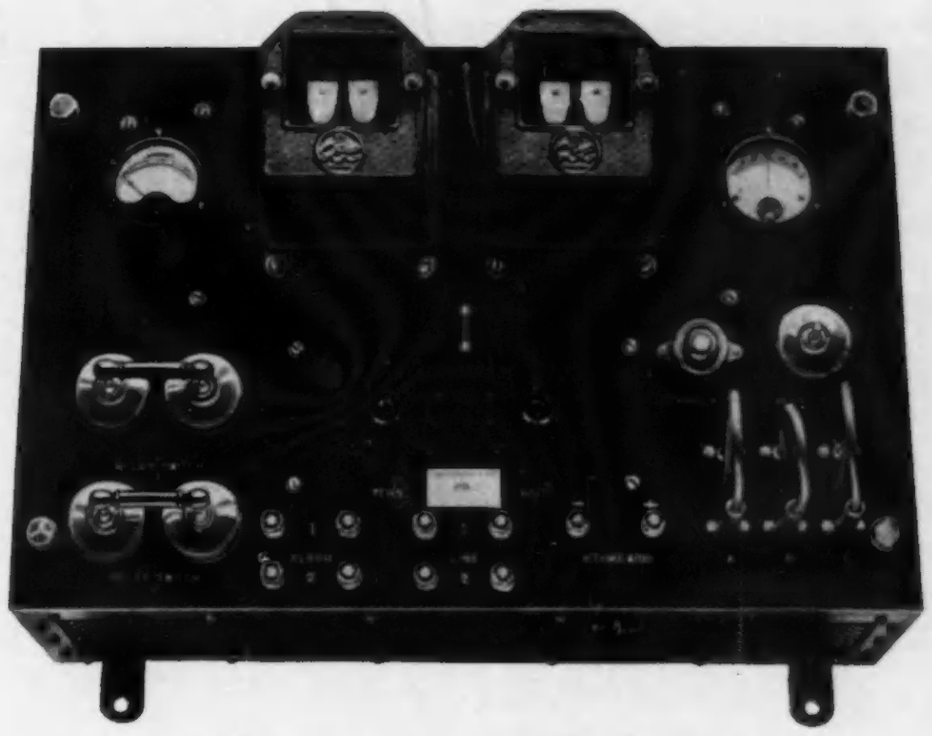
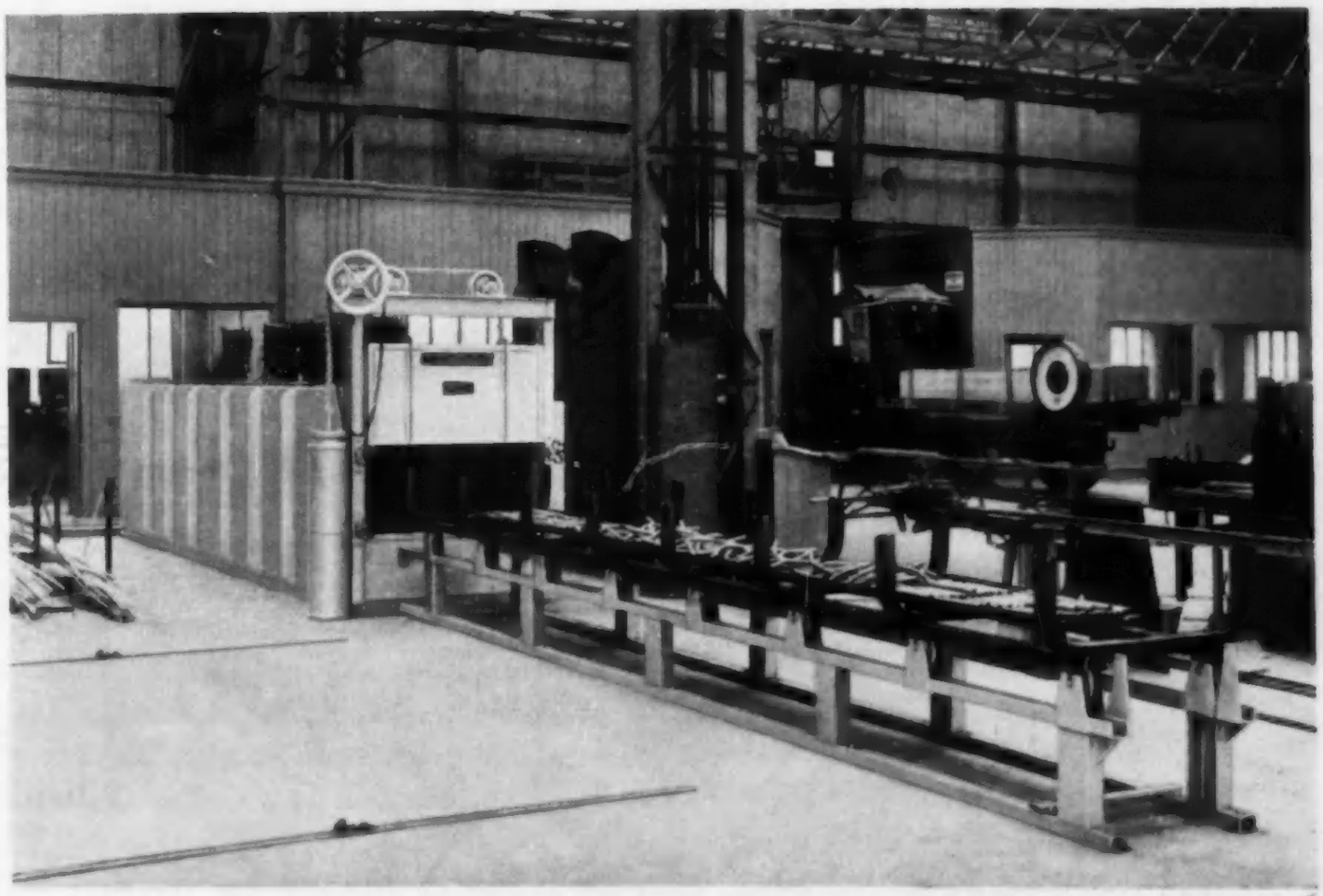


Fig. 17.—Panel employed in connection with leak indicator.

Electric Furnace for Ageing Aluminium Alloy Products.



A 40 kW Magnet low temperature electric furnace for ageing hiduminium R.R.56 alloy tubes, rods and sections in the Hay Hall Works, Birmingham, of Reynolds Tube Co., Ltd.

Colour Floodlighting with Electric Discharge Lamps.

By R. O. ACKERLEY,
Illuminating Engineering Dept. of The General Electric Co., Ltd.

The general principles of the operation of electric discharge lamps, and the stage to which these had been developed by the Research Laboratories of The General Electric Company were discussed by C. C. Paterson in Vol. IV, No. 1, page 46 of the G.E.C. Journal. The practical development of the "Osira" street lighting lamp was further dealt with by J. W. Ryde (Vol. IV, No. 4, page 199). The object of the present article is to discuss another development of the electric discharge lamp, namely, the "Osira" system of colour floodlighting.

It is of interest that the coloured illustrations shown in the frontispiece (page 188) and on pages 219 to 222 are reproduced from untouched colour-photographs.

TO appreciate the potentialities of "Osira" colour floodlighting lamps in the colour lighting field, it is necessary briefly to examine the basic principles governing the production of coloured light.

THE PRODUCTION OF COLOURED LIGHT.

Considering the radiation of light from an incandescent body such as the sun or the filament of an electric lamp, radiations of various wavelengths are emitted by such a body, but only a small proportion of the total energy radiated falls within the limits of the visible spectrum. It is, however, a characteristic of the radiation from an incandescent body that while the relative proportions of energy emitted at different wavelengths may vary, there is some radiation over the whole range of the spectrum.

Now the colour of a given light is a function of the wavelengths of which it is composed, and in the past to obtain coloured light it has been necessary to take the light from an incandescent light source such as an electric filament lamp, and by a process of absorption cut out the light rays of unwanted wavelength, leaving only those giving predominantly the colour required. This is clearly a most uneconomical process as the rays which are cut out are simply wasted, and in many of the colours used in practical colour lighting the absorption of the colour producing media is 80 per cent or more. If a light source could be produced which would radiate the whole of its energy in certain required wavelengths only, instead of spreading it over the whole range, light of the colour corresponding to the selected wavelengths could be obtained without the absorption of any unwanted rays.

Assuming the colour in question to be one for which an 80 per cent absorption medium would normally be required, then if the new light source had only half the overall efficiency of the old source but radiated all its light in the required colour, it would still give 2½ times as much light in the selected colour, *i.e.*, 50 per cent as against 20 per cent of the original overall light output.

In the electric discharge lamp such a light source is available, for the light radiation from an electric discharge in a gas or vapour is only emitted in wavelengths characteristic of the gas, and is not spread over the whole spectrum.

THE SENSITIVITY OF THE HUMAN EYE.

Before considering the characteristics of the various gases and vapours available, there is one other factor of coloured light production which should be appreciated. This is the fact that the relative sensitivity of the eye to light of various wavelengths is

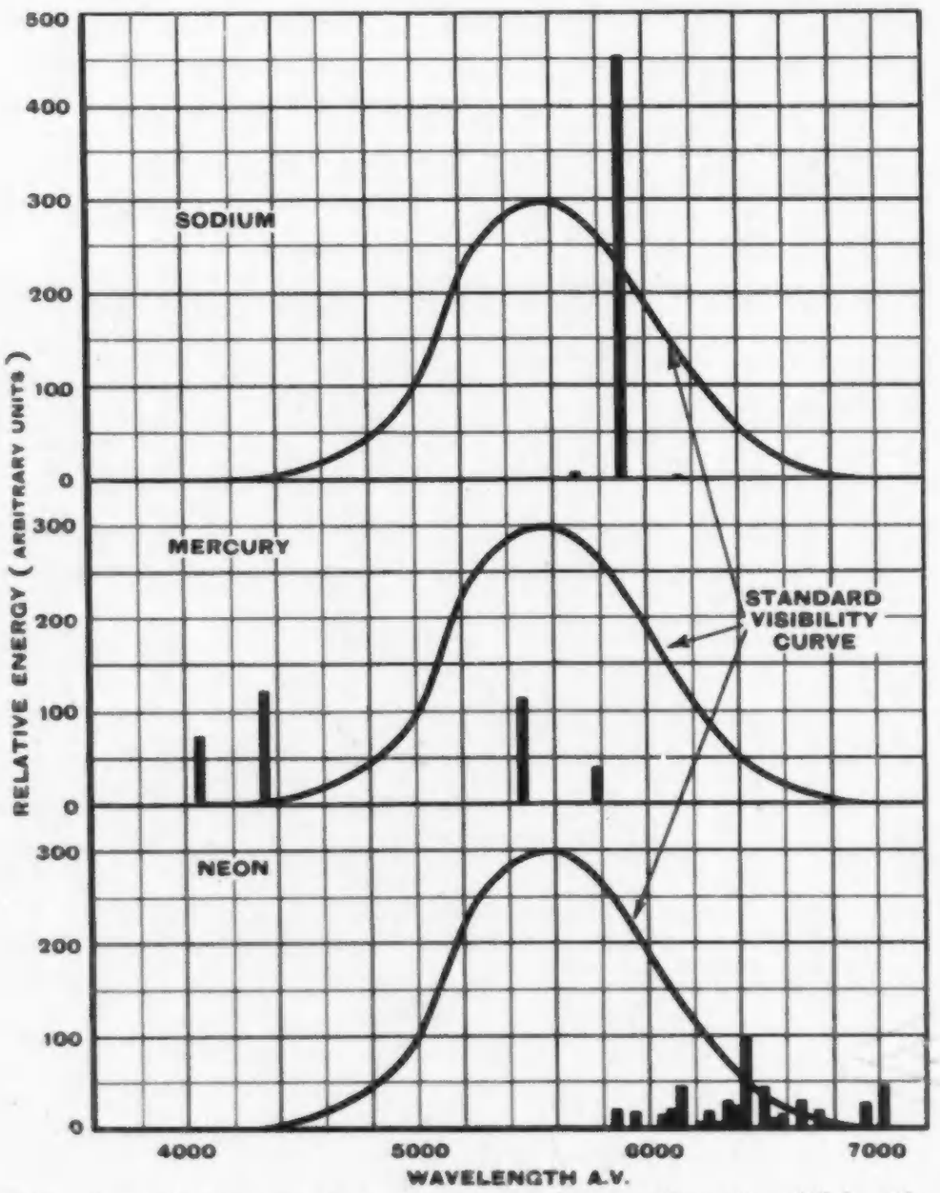


Fig. 1.—Diagram showing energies radiated within the visible spectrum of discharge lamps consuming equal wattages, and the position on the standard visibility curve at which such radiation occurs.

not constant, and the measurement of light output from any given light source is as much a function of this eye sensitivity as it is of the energy radiated (figs. 1 and 2). For this reason assuming a given percentage of total input energy is radiated within the visible rays, the light output will increase or decrease according to whether the radiation is in

Fig. 3.—Standard "Osira" floodlighting lamp.

the parts of the spectrum to which the eye is more or less sensitive. The high efficiency of the "Osira" high pressure mercury lamp is due not only to an increased percentage of radiation within the visible spectrum, but also to the fact that such radiation takes place largely in those parts of the spectrum to which the eye is particularly sensitive.

When dealing with colour lighting the colours cannot be chosen according to eye sensitivity;

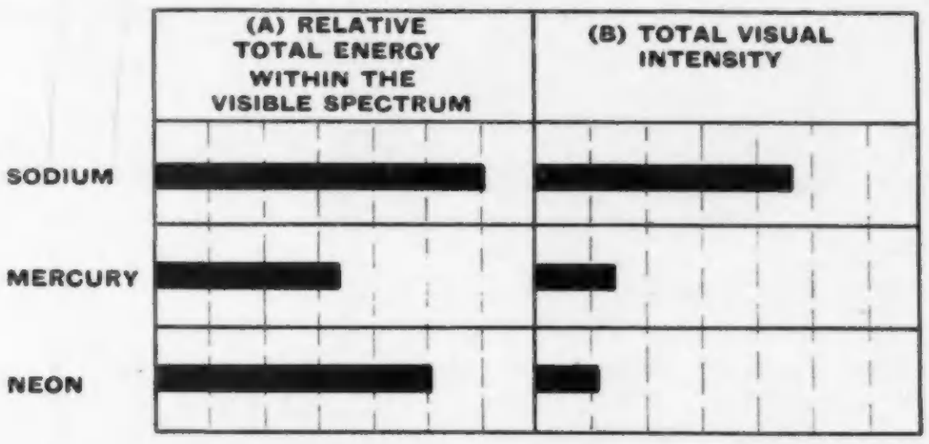


Fig. 2.—Comparison of discharge lamps. (A) represents the sum of all the energies shown in fig. 1; (B) represents the sum of these energies multiplied respectively by the appropriate visibility factor as shown on the standard visibility curve.

but as wide a range as possible has to be produced with the means available.

The variation in eye sensitivity partly accounts for the discrepancy between the overall light output of a neon discharge lamp radiating in wave lengths to which the eye is relatively insensitive, and that of a sodium vapour lamp the light from which is emitted in wave lengths close to that at which the eye sensitivity is greatest. There is frequently a serious misconception however as to the effect of this eye sensitivity. It has been stated for instance, that not only are sodium lamps highly efficient, giving a luminous output of 40 lumens per watt or more, but that as this output is in a colour to which the eye is particularly sensitive, the effect on visibility would be correspondingly greater. This is a complete misunderstanding of the position, as the sensitivity of the eye has already been taken into account when estimating the lumen output. In other words, the measurement of lumen output is actually a determination of the eye's reaction to the particular radiation, and if the argument set out above be used, the eye sensitivity factor is credited twice over.

EFFICIENCY OF COLOUR FLOODLIGHTING LAMPS.

Having briefly examined some of the factors controlling coloured light production, it is now convenient to consider what "Osira" floodlight sources are available, and how, in practice, they compare in efficiency and other qualities with light of apparently similar colours, but obtained from an incandescent lamp and a colour filter.

In speaking of light of apparently similar colour, it is recognised that the response of the eye to any particular coloured light will vary with individuals. This applies especially where the composition of two similarly coloured lights is different, as is the case when a continuous spectrum light is being synthetically matched by means of colour media with a light which obtains its colour from radiation on a few wavelengths. In the same way it is appreciated that ordinary commercial colour media, whether glass or gelatine, vary considerably from batch to batch, but the figures given in the following tables may be taken as accurate within a small percentage of error for the normal eye.

The original lamps for "Osira" colour floodlighting gave red and blue light. Red came from neon,

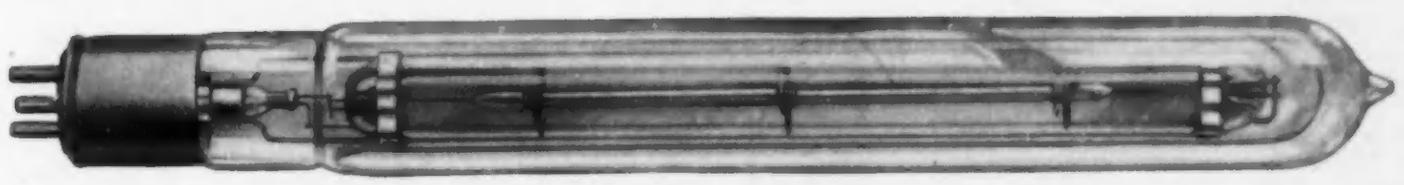


Fig. 4.—"Osira" sodium floodlighting lamp.

and blue from mercury. Mercury also gave, with the aid of special glasses, two shades of green. It is interesting to note that while the conversion of the direct mercury discharge to dark green involves some loss in overall efficiency, by the use of a fluorescent glass, the light green lamp has slightly greater lighting efficiency than the natural light blue.

When first developed, the overall efficiency in

lumens per watt for the red, light blue and green lamps, was in the neighbourhood of eight lumens per watt, and for the dark green, six lumens per watt. A year's development has produced marked improvement in efficiency without any loss of life, and the figures to-day, in the case of the green and blue lamps, are 50 per cent. higher, while the red efficiency is increased over 10 per cent. This improved efficiency in the blue lamp has justified the addition of a dark blue lamp to the range.

In the same period a floodlight using a sodium lamp has been introduced so that the present range covers six colours, red, yellow, two shades of green and two shades of blue.

Table I.

EFFICIENCIES OF "OSIRA" ELECTRIC DISCHARGE LAMPS.

Colour of light.	Nature of Discharge.	Overall Watts.	Overall Efficiency in lumens per watt
Red	Neon	470	9.5
Light Blue ..	Mercury	340	12.0
Dark Blue.. ..	,,	320	4.2
Light Green ..	,,	340	12.0
Dark Green ..	,,	340	9.0
Yellow	Sodium	100	38.0

Table II.

EFFICIENCIES OF INCANDESCENT TUNGSTEN LAMPS WITH AND WITHOUT COLOUR FILTERS.

Watts.	Efficiency of normal Incandescent lamp.	Colour of Light Filter.	* App. % Transmission of Filter used to provide these colours.	Net L/w of coloured light.
470	15.0	Red	30	4.5
340	14.0	Light Blue	30	4.2
320	14.0	Dark Blue	10	1.4
340	14.0	Light Green	30	4.2
340	14.0	Dark Green	25	3.5
100	12.0	Yellow	70	8.4

***N.B.**—These values are approximate only and represent the order of transmission of commercial gelatines used in front of tungsten sources to obtain coloured light which in appearance is similar to that from the respective discharge lamps.

Table III.

COMPARISON OF DISCHARGE LAMP EFFICIENCIES WITH THOSE OF INCANDESCENT LAMPS USING COLOUR FILTERS.

Colour.	Efficiency of Discharge Lamp from Table (1). Col. 1.	Efficiency of modified Incandescent Lamp. Col. 2.	Col. 1. / Col. 2. × 100
Red	9.5	4.5	210
Light Blue ..	12.0	4.2	286
Dark Blue ..	4.2	1.4	300
Light Green ..	12.0	4.2	286
Dark Green ..	9.0	3.5	257
Yellow	38.0	8.4	452

The above tables give the luminous output in terms of lumens per watt for all these lamps as compared with the efficiencies of correspondingly coloured incandescent lamp and colour medium combinations. The figures given for the "Osira" lamps are overall efficiencies after allowing for choke losses, etc., the efficiencies of the lamps only being even higher than the figures given.

It will be seen, therefore, from Table III that the efficiency of the discharge lamp is about double that of the tungsten lamp in the case of the red lamp, and over four times in the case of the yellow sodium light.

"OSIRA" FLOODLIGHTING LAMPS.

The mercury and neon lamps are made up in the form of a tube approximately 4ft. long, capped at either end with a two-pin plug. The electric discharge takes place in this tube, the luminous column being 34in. long. They will work in any position and off any A.C. supply voltage between 200 and 260 volts.

The sodium lamp is very much shorter and capped at one end only with a three-pin cap, the overall length being 16ins. and the length of the actual light column 9ins. It will operate on similar supplies to the mercury and neon lamps, but should only be burnt horizontally.

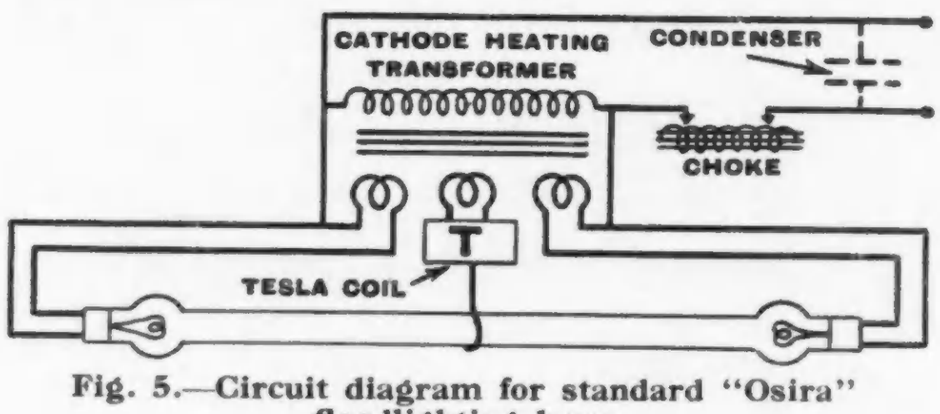


Fig. 5.—Circuit diagram for standard "Osira" floodlighting lamp.

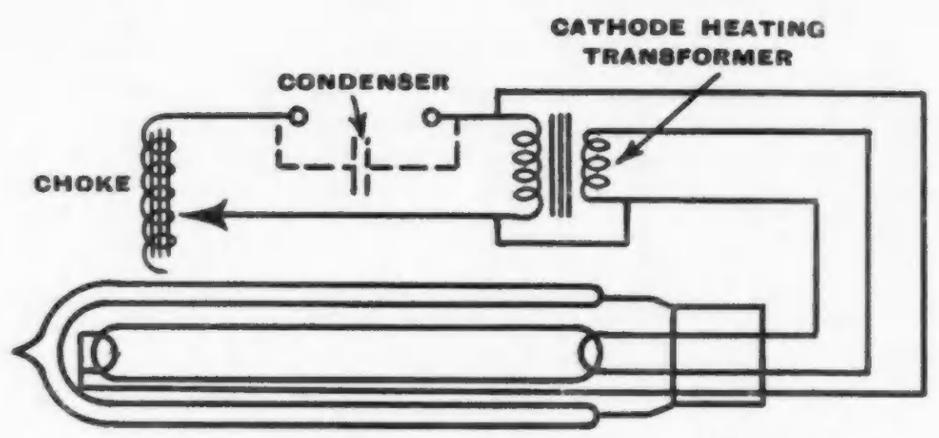


Fig. 6.—Circuit diagram for "Osira" sodium floodlighting lamp.

THE RUNNING OF "OSIRA" FLOODLIGHTING LAMPS.

The function of the choke in controlling electric discharge lamps has been sufficiently explained in the two articles referred to at the outset of this article, so that it will be sufficient to say that with the mercury and neon lamps the standard controlling equipment consists of a choke, a small transformer to heat the cathodes, and a "Tesla" coil which operates to start the discharge and cuts out automatically as soon as the arc is formed. In the case of the sodium lamp the "Tesla" coil is not required.

The circuit diagrams for the two types of lamps are shown in figs. 5 and 6. The power factor in all cases is approximately 0.3, but this can be

Colour floodlighting of open air swimming baths at New Brighton.

Warren Street Station, London Electric Railways, illuminated by "Osira" sodium floodlights.

Buckfast Abbey floodlighted with a combination of Osram gasfilled lamps and "Osira" colour lamps.

A colour floodlighted garden. Note the underwater decorative units in the ornamental pool.

corrected to 0.8, and upward, by the installation of condensers, 80 μF being required for each mercury and neon tube, and 20 μF for the sodium lamp.

THE REFLECTING EQUIPMENT.

The practical application of the "Osira" colour lamps to floodlighting problems has involved an investigation into the best method of controlling the light distribution from a light source of an entirely new shape and size. The nature of the source imposes certain limitations in that with a light column 34in. long it is quite impossible to concentrate the light into a narrow symmetrical beam. On the other hand, such a light column lends itself particularly easily to wide diffusion in a plane through the lamp axis, combined with concentration in a

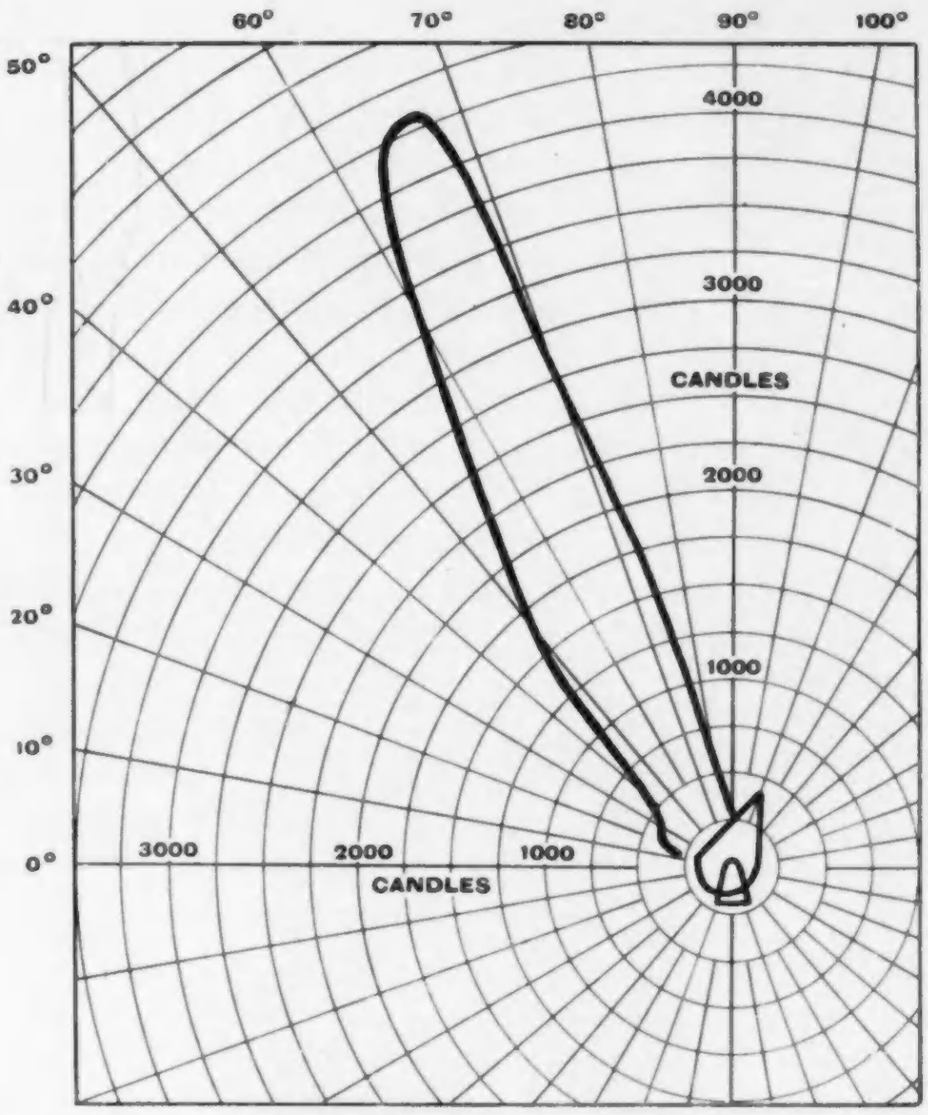


Fig. 7.—Curve of light distribution in a vertical plane for standard floodlight equipped with "Osira" light blue (mercury) floodlight lamp.

narrow angle in a plane at right angles to it, *i.e.*, a fan of light. Such distribution is very suitable for a high proportion of floodlighting problems in which it is required to spread the light over large flat areas such as the walls of buildings. In this way, while the illumination of a church spire would entail considerable wastage, the lighting of a facade can be carried out from a limited offset far more evenly, and with far less light wastage, than is possible with any type of standard incandescent lamp floodlight. Actually, the design of a reflector to give a high degree of concentration in one plane has involved the working out of an entirely new reflector technique, as unlike the filament in tubular incandescent lamps, the light source, instead of being—from the practical point of view—a line of no

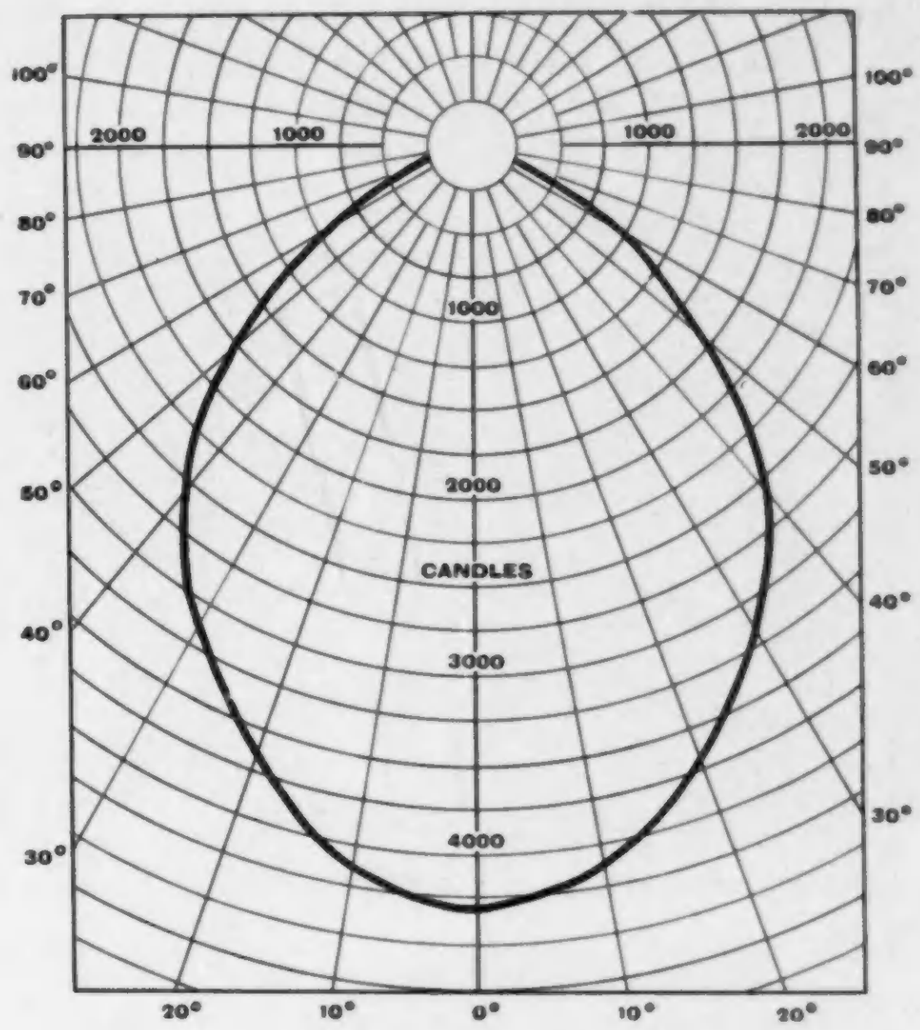


Fig. 8.—Curve of light distribution in plane of maximum intensity.

appreciable breadth, is a solid column of quite appreciable dimensions. In spite of this difficulty a reflector has been produced which satisfactorily copes with a very large proportion of floodlighting problems, and allows considerable latitude in the height-offset ratio. At the same time the wide distribution in the one plane permits of a high spacing-offset ratio without loss of evenness of illumination (figs. 7 and 8). The standard reflector, whose evolution has just been referred to, is of mirror glass, but where less concentration is required a vitreous enamel, or matt aluminium reflector, can be substituted, thereby increasing still further the number of installations for which suitable distribution can be found.

THE FLOODLIGHT UNIT.

The standard floodlight unit for use with the neon and mercury lamps consists, therefore, of a weatherproof metal housing, fitted with a heat resisting front glass, and mounted on trunnions which allow of adjustment to the angle of tilt. In this housing are placed the reflectors previously described, comprising a trough section and two flat end pieces, while inside one end of the housing are placed the "Tesla" coil and transformer. The chokes and condensers can be installed anywhere convenient in the circuit, between the main switch and the

floodlight. In an installation of a number of units, the chokes and condensers are generally placed adjacent to the main controlling switch. The lamp is held in the floodlight by suitable metal clips, and no focussing device is provided as with the lamp supported at both ends the position can be fixed to a high degree of accuracy, and the thickness of the light column further ensures that small alterations in focal position will not materially affect the reflected beam.

The general arrangement of the sodium floodlight follows the same lines as that for the neon and mercury lamps, but the housing is very much smaller, and the "Tesla" coil is omitted. The transformer is housed inside the floodlight.

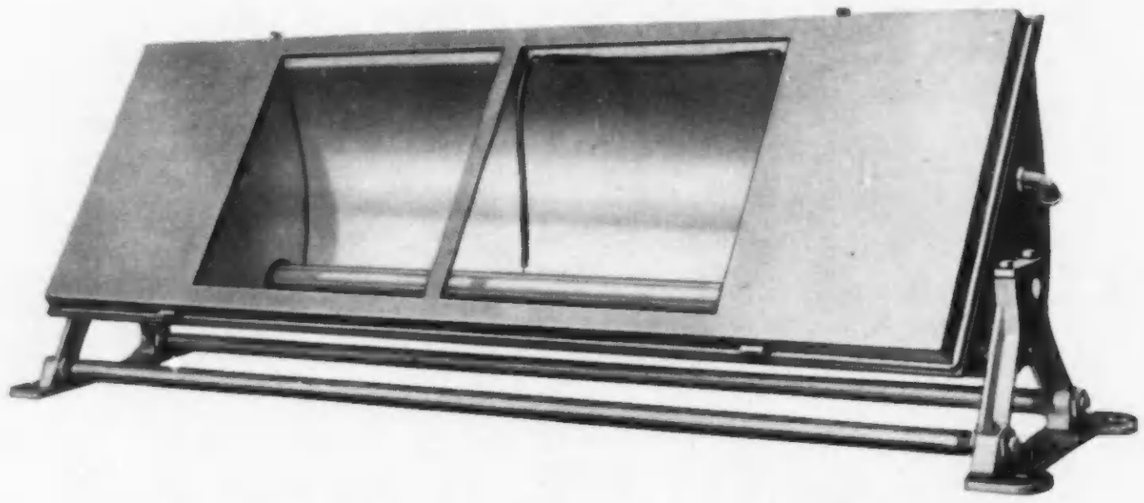


Fig. 9.—Floodlight unit for "Osira" floodlighting lamp.

PRACTICAL ADVANTAGES OF "OSIRA" FLOODLIGHTING.

The advantages which these "Osira" floodlighting lamps offer in the solution of practical floodlighting problems will now be considered.

For many years colour lighting has been employed for a variety of purposes, the coloured light being obtained by interposing colour media in the rays from an incandescent light source. Electric discharge colour lighting lamps can be used for the bulk of these applications affording a number of advantages, the principal of which are :—

(1) Their higher efficiency, which has already been sufficiently discussed.

(2) Their complete colour constancy. The light transmission of commercial colour media, whether of glass or gelatine, is liable to vary from batch to batch, quite apart from the variations due to the alteration of the colour of the light from the incandescent lamp on account of normal mains voltage fluctuation. It is no uncommon occurrence to test out colour media to obtain the best effect on a given installation, and to find, when bulk deliveries are made against the agreed test sample, that an entirely different result is obtained. In the case of electric discharge lamps, within the limits of any normal or reasonably abnormal voltage fluctuation, the colour of the light emitted remains constant throughout life, and once a given effect has been approved, it can be repeated with full confidence in the result. The full potentialities of the colour constancy of these lamps have not yet been commercially appreciated, and there will undoubtedly prove to be certain specialised applications for which this quality will prove of vital import.

(3) Their capacity for taking advantage of the selective reflection properties of the objects on which the light falls. Perhaps the best illustration of this is obtained from a comparison of the effect of lighting a red brick building with ordinary incandescent lamps and "Osira" red lamps. In spite of the fact that the ordinary incandescent lamp is rich in red rays, the effect of floodlighting red brick with incandescent light has always been unsatisfactory, the brickwork has appeared to be drab and lifeless. Under the "Osira" red, however, the colour of the brickwork springs to

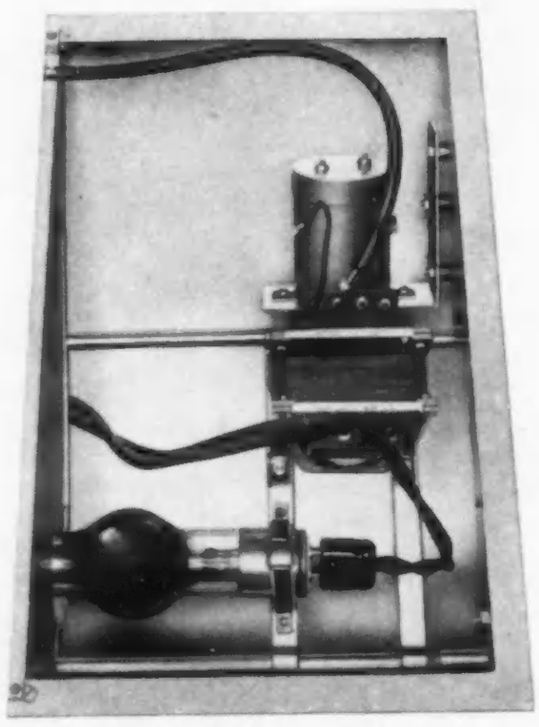


Fig. 10.—Detail view of the control gear.

life and every brick seems to glow like a red-hot coal. Another illustration is gained from the effect of lighting flowers and shrubs in a garden with a mixture of lights of various colours. Under a white artificial light, the richness of colours and their contrast one against the other is very largely lost. Under the light from a battery of "Osira" lamps of different colours, each flower seems to select the particular rays to which it best responds, and ignores the others. The roses reflect a rich red, the foliage takes on a vivid green, the yellows, oranges and blues all respond to the rays which emphasise the brilliance of their colours.

Fig. 12.—"Osira" sodium floodlighting units mounted on the top of Warren Street Station, London Electric Railways.

In this connection, however, it is only right to sound a warning note as regards the use of sodium lighting. As is well known the light from the sodium discharge is practically monochromatic being confined almost entirely to two lines in the yellow portion of the spectrum, and the relatively high efficiency of this lamp is due to the fact that these rays fall in a part of the spectrum to which the eye is highly sensitive. The fact, however, that the light is so limited in colour constituents means that objects which are incapable of reflecting these particular wave lengths will appear black or

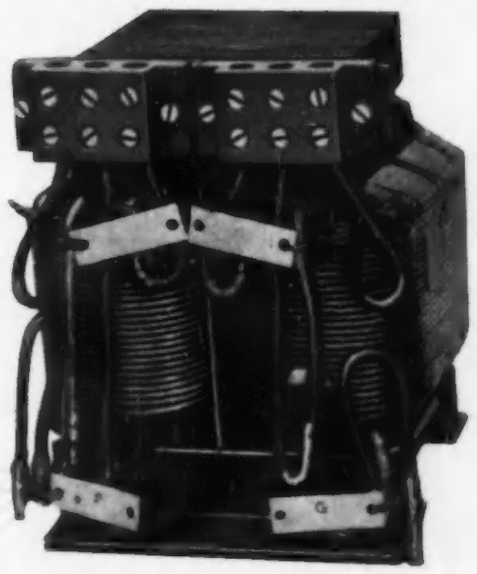


Fig. 11.—Choke for "Osira" floodlighting lamp.

grey, and for this reason the sodium floodlight, the natural light from which appears rich and warm when viewed as reflected off a white surface, should only be employed for flooding on to a cream or whitish ground. Above all it is undesirable to employ the flood where the light may be thrown direct on to the human face. Rightly used, however, most attractive effects can be produced at a lower running cost than by any other equally effective means.

TYPICAL USES OF "OSIRA" COLOUR FLOODLIGHTS.

The actual purposes for which the lamps can be used to advantage are many, of which the following may be taken as typical.

For advertising purposes.—While for equal surface brightness the actual visibility of a building is no greater if it is illuminated in colour than if it is lit with white light, there is a psychological effect due to the relative uncommonness of coloured lighting, and the extent to which it contrasts with its surroundings. For this reason a building floodlighted in colour will appear to catch the eye quicker than one illuminated to the same intensity with white light. The advantages from an advertising point of view of lighting buildings on main roads and railway lines, are being increasingly appreciated, and apart from the psychological effect of colour mentioned, the use of coloured light may make possible the lighting to advantage of a building, *e.g.*, red brick, which by its own colouring does not respond effectively to white light.

For the lighting of public buildings, ancient monuments, etc.—It is now accepted that there is no necessity for beautiful buildings to be invisible after dark, and that floodlighting provides an inexpensive method of making it possible for such buildings to continue to give pleasure as much at night time as by day. Many such buildings look exceedingly well under the soft glow of red floodlighting, but where, as may often be the case, red or dark green lighting is considered too garish and too undignified,

the soft light from the light blue and green lamps can be used without any misgiving, and an effect akin to brilliant moonlight will be obtained. Under such a light old grey stone appears to peculiar advantage.

For the lighting of public and private gardens.—As already described, the colours of the lamps have the power to bring out the colours of foliage and flowers.

For mass decorative lighting.—The effect of light as a means of attracting visitors to a town has been proved on many occasions, and at many places. A very well-known example is afforded by the annual illuminations at Blackpool for which over one hundred "Osira" floodlights were employed last year. For such illuminations the electric discharge lamp is ideal.

For interior decorative lighting.—Striking interior lighting effects can be obtained, and particularly can the decorative possibilities of cross colour shadows be exploited. The wide variety, and the beauty of the effects which can be obtained by lighting mouldings, beams, etc., with different colours from different angles, must be seen to be appreciated.

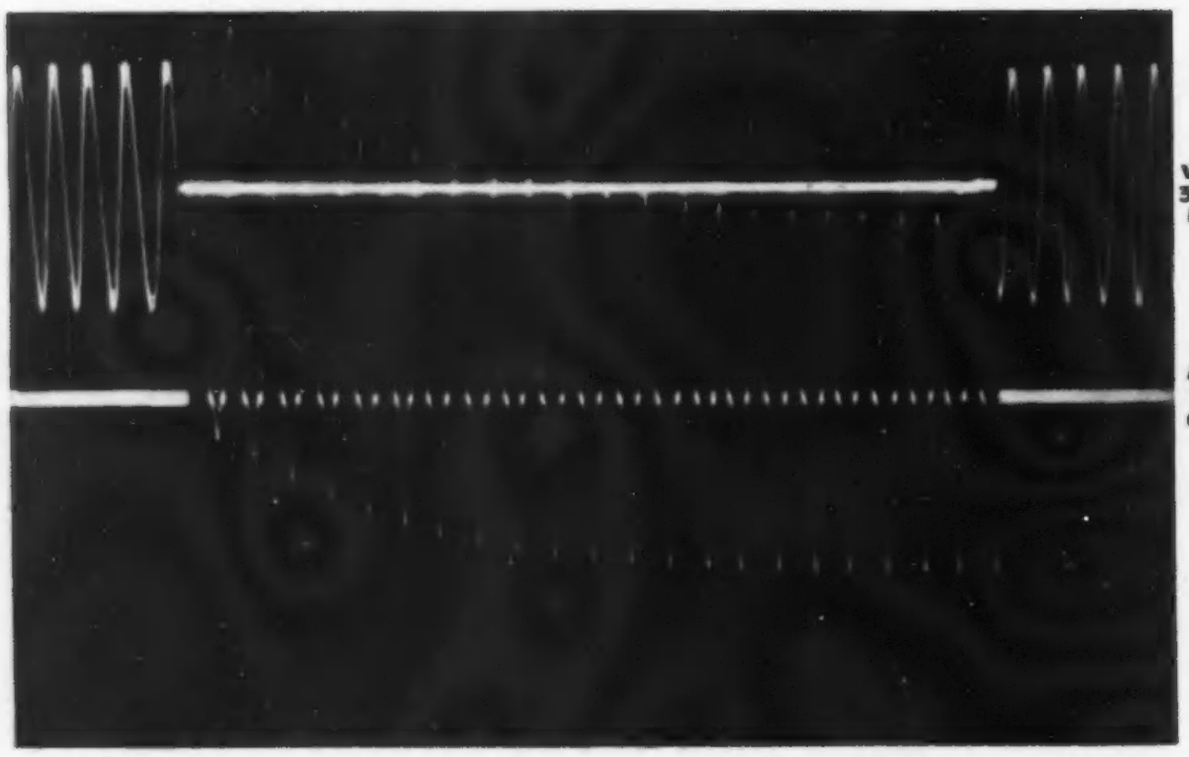
The mixing of colour.—The mixing of light from different coloured electric discharge lamps in order to obtain white light is not often advisable, as, while a good white can be obtained, it is only when the lamps are used to produce coloured light that full advantage can be taken of their high efficiency. Mixing of light can, however, be used to advantage for two purposes already mentioned, namely, the production of colour shadows, and the illumination of coloured articles having the power of selective reflection.

In conclusion, some special reference must be made to the possibilities of employing the high pressure mercury lamp for floodlighting purposes.

While there is no reason why full advantage should not be taken of the high lumen output available, the fact that, unless special magnetic controls are introduced, the lamp can only be burnt vertically, has introduced certain complications connected with the design of a reflector which will give satisfactory distribution for a reasonable proportion of typical floodlighting installations. Without such a reflector all the advantage of the initial high efficiency is liable to be offset by waste of light and unevenness of distribution. A reflector design and housing has now been evolved which will give suitable light distribution in a large proportion of cases, and will allow of tilting and adjustment to the main beam without any necessity for tilting the lamp itself. Alternatively, as indicated above, special magnetic controls can be introduced into a floodlight housing so as to permit of the lamp being burnt horizontally, in which case light distribution characteristics generally similar to those described for the colour floodlighting lamps can be obtained. Naturally, however, this additional equipment increases the cost as well as introducing a complication which may adversely affect the life of the lamp.

Oscillogram Test of an Oil-immersed Wing Isolator.

The oscillogram reproduced illustrates the results of a make-and-break test made on a 6,600 volt, oil-immersed wing isolator designed to isolate a section of a ring main. The normal current rating of the isolator was 300 amps. Tests were carried out to represent these conditions, the voltage being adjusted to 3,800 volts, which corresponds to the voltage to neutral of the system.



It will be seen that the test shown by the oscillogram was particularly severe, the current on closing being entirely asymmetrical, giving a full doubling effect. The current broken was 750 amps R.M.S. while the making current was actually 1875 amps peak value. After the tests, examination showed no burning of the current carrying faces and no perceptible lowering of the dielectric strength of the oil. The oscillogram was taken after making and breaking 14 times.

Electrical Equipment for the British Grid.

PART V.—PROTECTIVE GEAR FOR GRID FEEDERS.

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Development Laboratory, Witton Engineering Works of The General Electric Co., Ltd.

This is the fifth and last of the series of articles describing the electrical equipment supplied by the G.E.C. to the Central Electricity Board for use on the British grid.

The four previous articles dealt with (1) *Outdoor Substation Equipment* (2) *Towers, Transmission Lines and Cables* (3) *Metering Equipment, and* (4) *Communication Equipment, and appeared in Vol. IV, No. 4, Vol. V, Nos.* 1, 2 *and* 3 *respectively.*

THERE are two vital considerations which must be satisfied when a co-ordinating system of feeders such as the British grid is super-posed upon an existing set of supply networks.

First, the running cost, and secondly, the risk of shutdown, must not be greater than before the interconnection was carried out. It is because of the second condition that the design of the protective gear is of outstanding importance, an importance which is enhanced not only since an additional E.V.H. link has been added to every transmission, but also because a single breakdown will in general affect a much larger area of supply than previously.

G.E.C. protective gear has been installed in several of the areas into which Great Britain has been divided. Moreover, it has been designed for lines having widely different descriptions as regards voltage, length, position in the network, and type of station or substation from which they run. The characteristics of the schemes employed have accordingly been modified to suit the respective locations and duties, with the result that gear based upon a number of quite distinct principles has been utilised.

TYPES OF SCHEME.

The various types of protective scheme concerned are as follows:

(1) Standard three pilot (based on McColl patents).
(2) Single or two pilot (based on McColl patents).
(3) Parallel interconnector.
(4) Duplex.
(5) Negative phase sequence, or unbalanced phase.

These schemes will be dealt with in turn, and their characteristics will be discussed in conjunction with the type of feeder for which each has been employed.

1. STANDARD THREE-PILOT PROTECTIVE SCHEME.

The standard scheme depends on a comparison being effected between the current entering a section of feeder and the current emerging. When there is an excess passing in to the extent of say 10 or 20 per cent of the total current flowing at any instant, the relay trips and the section of feeder is isolated. It is the fact that the fault setting depends on the load at the time and has therefore a floating value, that gives this system its great advantage over other methods. By virtue of this biassing principle, an exceptionally sensitive setting obtains over the range of working loads, while for through faults, when current transformers are apt to become unbalanced, the setting automatically rises to a completely stable value.

The scheme used on the shorter sections of the grid in Central England is shown in the diagram forming fig. 1, while the relays employed are illustrated in figs. 2 and 3. Both figures show the direct mode of action of the relays, which actually *weigh* the

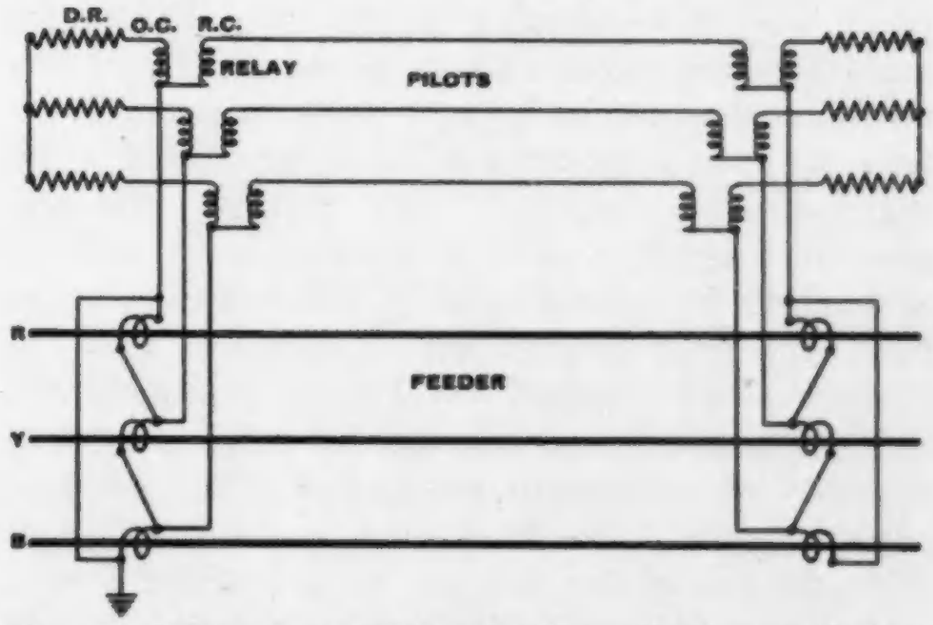


Fig. 1.—Delta-connected protective scheme earthed at one end only; used on Central England area.

pull of the current entering against that emerging. The knife-edge pivot of the beam is displaced a short distance in favour of the restraining coil, affording a very simple mechanical method of setting the proportionality that must exist between the two currents before tripping is effected. For the grid feeders this is fixed at 20 per cent.

In spite of the small number of components—only the "duplicate" resistances being required besides the current transformers and relays—the scheme deals correctly with capacity current in the feeder, capacity current in the pilot wire, and high frequency surges, without requiring any additional

Fig. 2.—Protective relay used on Central England area.

means such as are necessary to render other schemes stable. For all purposes ordinary cable is sufficient for the pilots, and the current transformers are of the ordinary instrument type without air gaps.

The grid installations have offered a good opportunity of demonstrating all the above features under the most exacting conditions. Before the contracts were placed, a test of the actual gear was arranged as shown in fig. 4, in order to establish the sensitivity and complete stability of the scheme under the specified conditions. The artificial pilot was given the high capacity of 4 microfarads, in addition to a resistance equivalent to 15 miles of pilot cable. First, the fault settings were ascertained over the working range by means of the lower network in the figure, which included resistors for varying the load and the fault currents independently. The resultant curve is given in fig. 5 which shows that although the setting is as low as 5 per cent at about normal load, it ascends rapidly for overloads, being already about 25 per cent at three times normal load. In addition, the setting is sufficiently high at no load to preclude tripping at that point by feeder capacity currents.

Secondly, a heavy current amounting to 36 times normal was passed through the primaries of the current transformers, and it was effectively demonstrated that the greater the overload, the more forcibly were the relays pulled into the "off" position, even if they were pushed down into the operating position by hand. It should be noted that the above current amounted to 9,000 amps. Actually the relays were modified before installation to give a characteristic curve with a lower value at no load and higher values elsewhere.

It happens that two successive feeder sections were run through a district situated in the heart of a heavily industrialized area, where the coating of insulators with a deposit of carbon, tar and other foreign matter was such that frequent scrubbing with a solvent proved the only method of preventing flash-over. Prior to the adoption of this procedure,

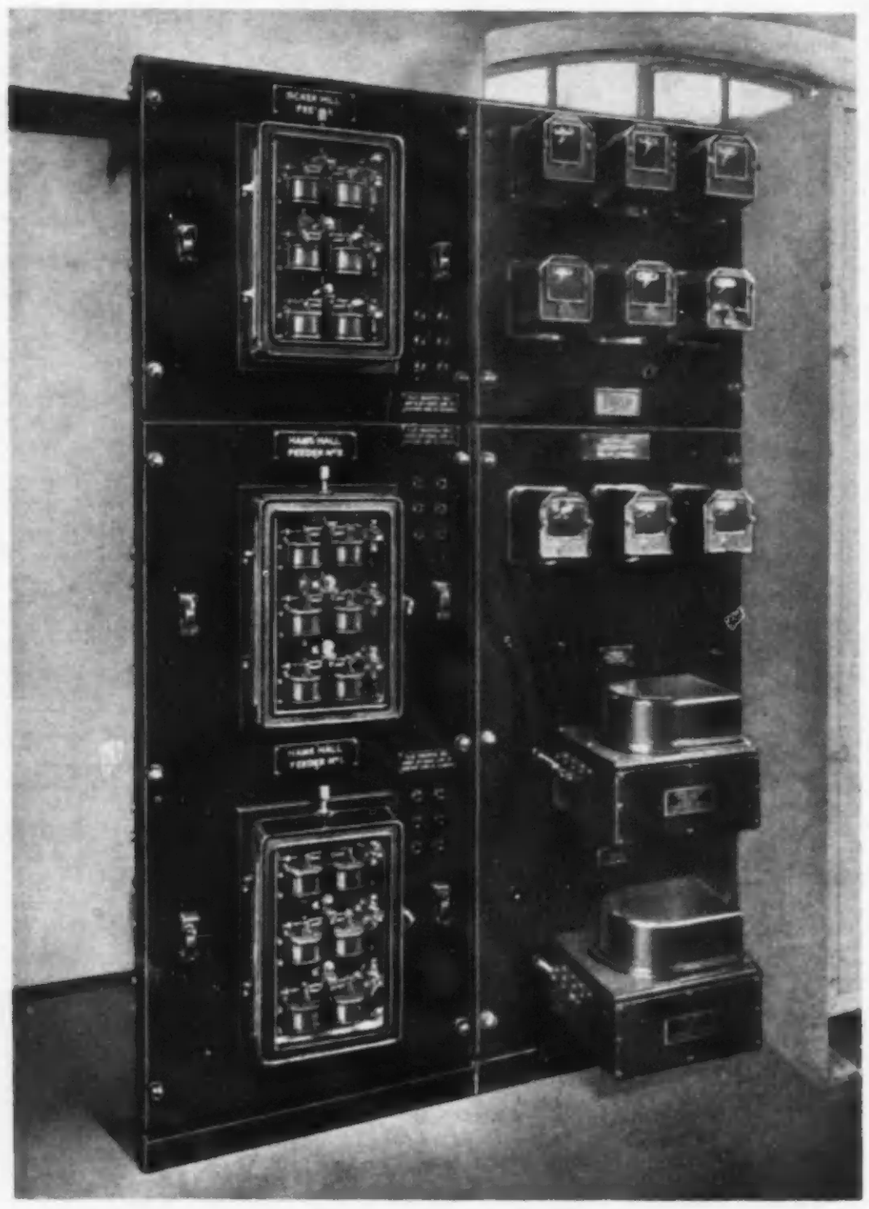


Fig. 3.—Protective relays at Nechells Power Station, Birmingham.

a series of short circuits occurred that effectively tested the relays in both sections; in the faulty one, for reliability of operation, and in the sound one, through which the fault current passed, for stability. In all respects, the scheme amply proved its efficiency. As one of these sections consisted of two parallel lines, each individually protected by this gear, it will be realised that the test was a particularly comprehensive one.

The chief impediment to the general use of the McColl system for all important feeders is the necessity for end-to-end pilots. When the lines are supported upon widely spaced towers, it is not

practicable to suspend the pilot cables from them; and in the case of the grid, with its 6-chain spacing, the pilots were in the form of cables buried near the base of the towers. This procedure is expensive and involves wayleave difficulties; and consequently the above type of scheme was restricted to the shorter sections of the 132 kV grid.

2. TWO-PILOT McCOLL SCHEME.

A method of reducing pilot wire costs is adopted in the two-pilot McColl scheme, which can be further simplified as a single-pilot installation with earth return. The root principle is the same as that of the standard scheme, but as shown in fig. 6, the current transformers are given different ratios and connected in parallel at each end. A difference current, proportional to the load, then flows in the single relay network, and any kind of fault causes this current to be greater at the one end of the feeder than the other, thus providing means for tripping the relay.

The scheme has the same general characteristics as the standard type, but requires higher fault-settings, 40 per cent being the usual value for typical cases. This value, however, is none the less lower

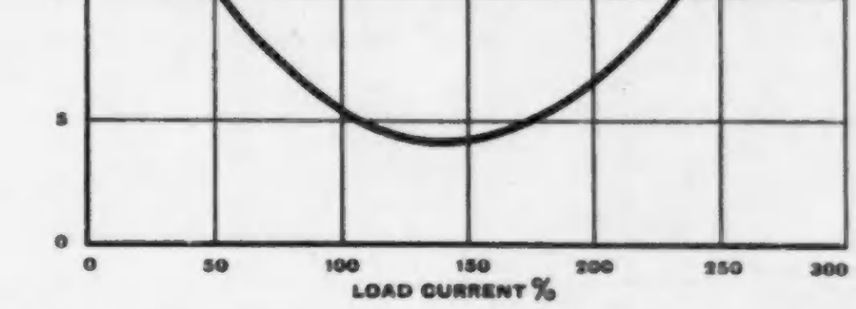


Fig. 5.—Characteristic curve for feeder protective gear.

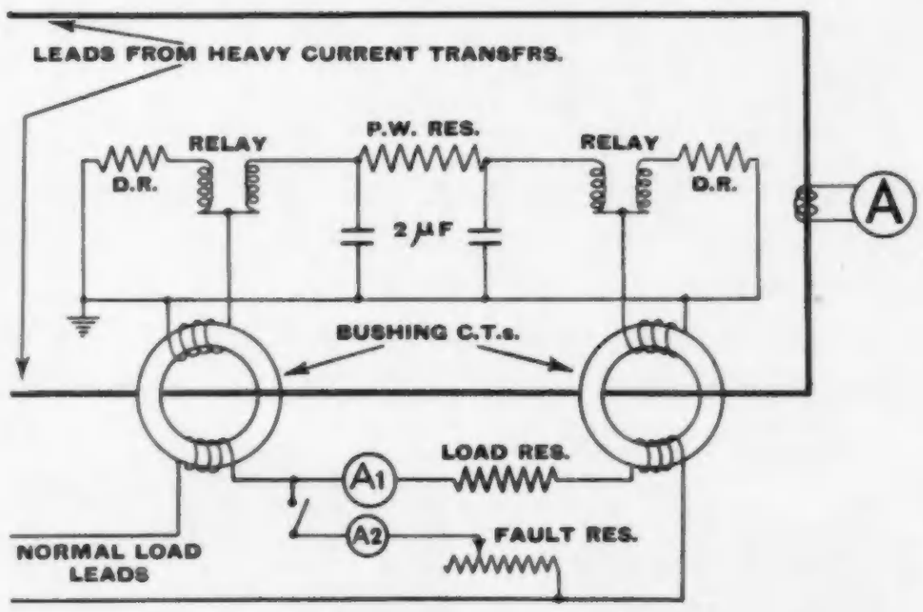


Fig. 4.—Layout of testing equipment for complete scheme.

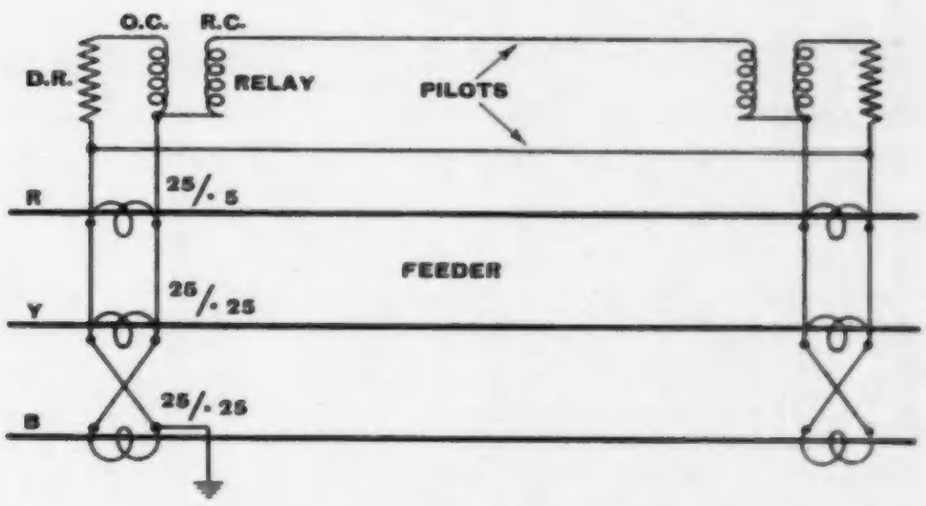


Fig. 6.—Two-pilot protective scheme.

than that given by the great majority of feeder protective schemes, and does not constitute a serious drawback.

A double installation was designed, tested, and accepted for a section of the Scottish grid; and although its installation has been delayed owing to wayleave difficulties in connection with the main feeders, it is worthy of description on account of the numerous features of interest it possesses. These will be gathered from the diagram forming fig. 7.

It will be seen that there are two feeders, each of which is protected by means of two pilots; but the latter are also employed for telephony on the "phantom-circuit" principle. In this, each pair of pilots is treated as a single telephone lead by making connection at each end through centre-tapped chokes. The voice-frequency currents pass through the latter since they flow in opposite directions and hence encounter no reactance; but the pilot current would have to pass through both sections of each choke in the same direction, and meet with a very high reactance. Tests proved that the operation of the protective gear produced no effect whatever upon the telephones, and *vice versa*.

Another important innovation promises the solution of the pilot-wire difficulty to which reference was made in the last section. In this installation, all four pilots are run in the centre of the overhead earth wire, thus adding an almost negligible amount to the cost. The new "earth core cable" developed by the Pirelli-General Cable Works at Southampton was specified, which incidentally has already been put into service in another part of the country.

The characteristics of the Scottish scheme are shown in fig. 8, which indicates the varying fault setting for the various phases, and also the order of sensitivity and the complete stability of the relays.

3. PARALLEL INTERCONNECTOR PROTECTIVE SCHEME.

When feeders are run in parallel, efficient protection can be given without end-to-end pilots by comparing the currents in the two lines, thus making one serve as a pilot to the other. The scheme for parallel feeders or interconnectors is indicated in fig. 9, and it is installed in this form in the North-West area of the grid. The relays are of the induction pattern, as shown in fig. 10, the potential windings not being shown in fig. 9. The inclusion of an electromagnetic biassing magnet in the upper part of the case gives the scheme all the advantages of those already described.

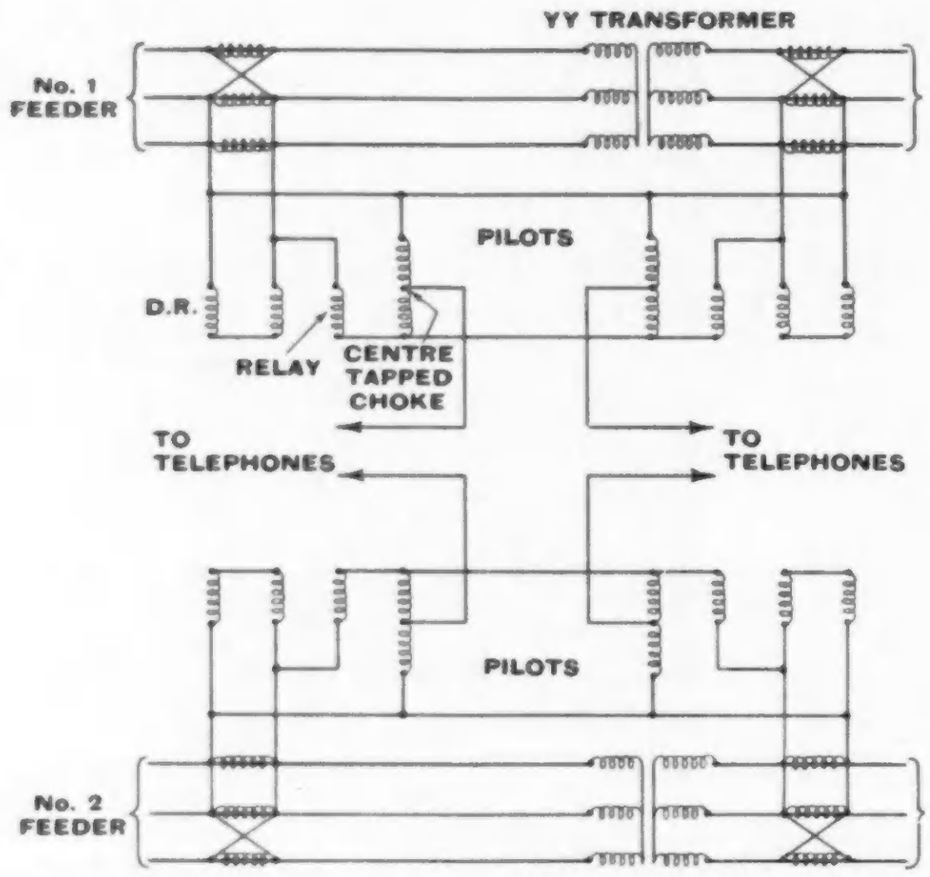


Fig. 7.—Schematic diagram of protective scheme used on South Scotland area.

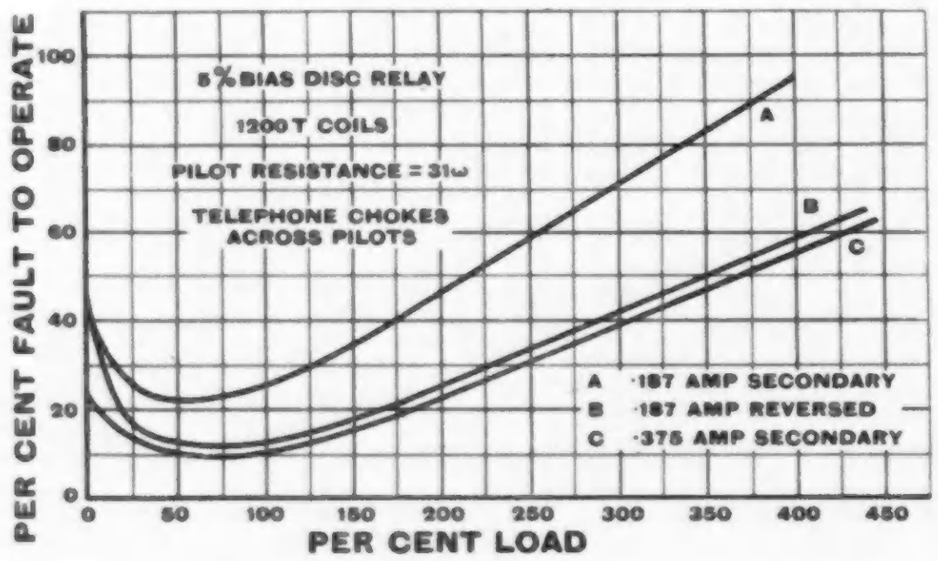


Fig. 8.—Double pilot feeder protection, faults to earth.

The tripping characteristics of the grid installation are shown by the test curves forming fig. 11. These show the high order of sensitivity and the very definite stability, reliable settings as low as 10 per cent being given. The curves also show the wide adjustments rendered possible. First, the no-load end of the curves can be varied by adjusting the spring setting, as registered on the scale in fig. 10; and secondly, the overload end can be independently varied by altering the position of the bias magnet, the smaller air-gap giving the higher degree of bias and *vice versa*.

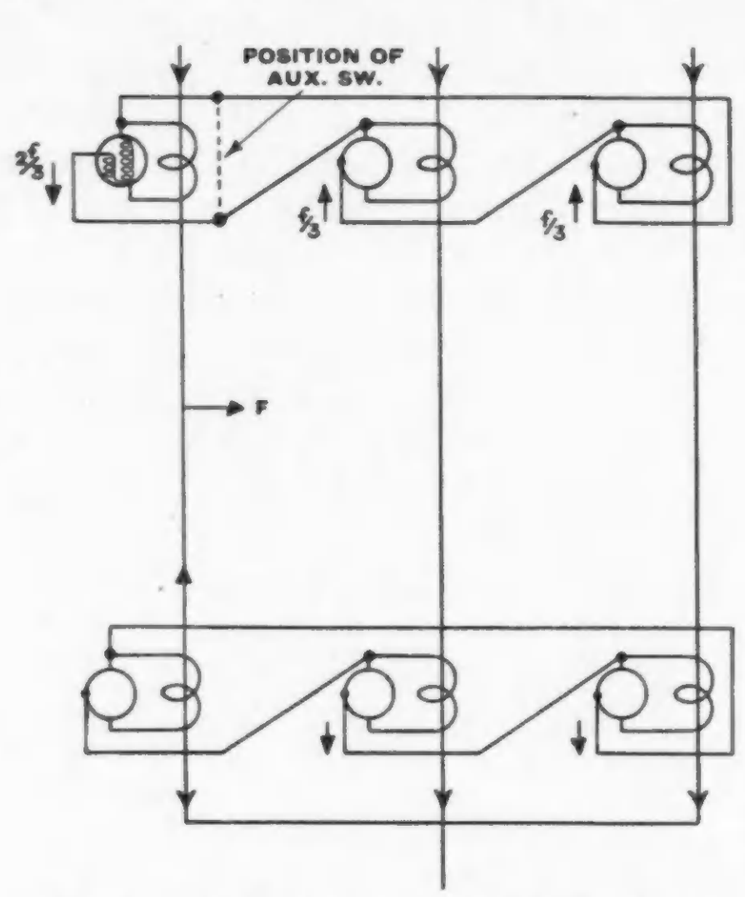


Fig. 9.—Parallel interconnector scheme.

It will be observed that a lower fault setting is always given by the relays at the home end, that is the end into which power is flowing at the time of the fault. This is a good feature, as it tends to ensure that the home end is disconnected first.

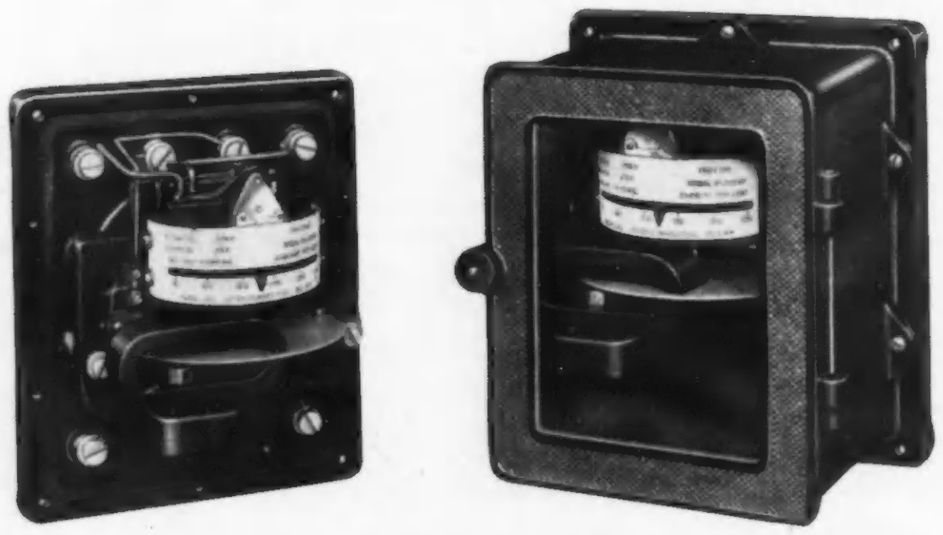


Fig. 10.—Biassed directional relay.

4. DUPLEX PROTECTIVE SCHEME.

The Duplex scheme is one depending on the signal current principle, and has already been described in the *G.E.C. Journal* (see Vol. III, No. 3,

August, 1932, page 142). An improved form has, however, been installed in a number of sections of 66 kV grid line in North-West England, the arrangement of which is shown in fig. 12. Its leading characteristics are first, that while a pilot channel is required, this has merely to carry a small D.C. signal current, not exceeding .015 amp. at 50 volts. This channel is much simpler to provide than the A.C. one or half amp. pilots required for the McColl system; and in the case of the grid feeders, telephone lines rented from the G.P.O. have been used. The second advantage is its absence of time lag, as compared with those pilot-less schemes that depend on delay for discrimination. It is well known that in the event of heavy short circuits in long feeders, the stability of the generating station depends on prompt disconnection, and an instantaneous system, such as those that have been described, possesses a big advantage in this respect.

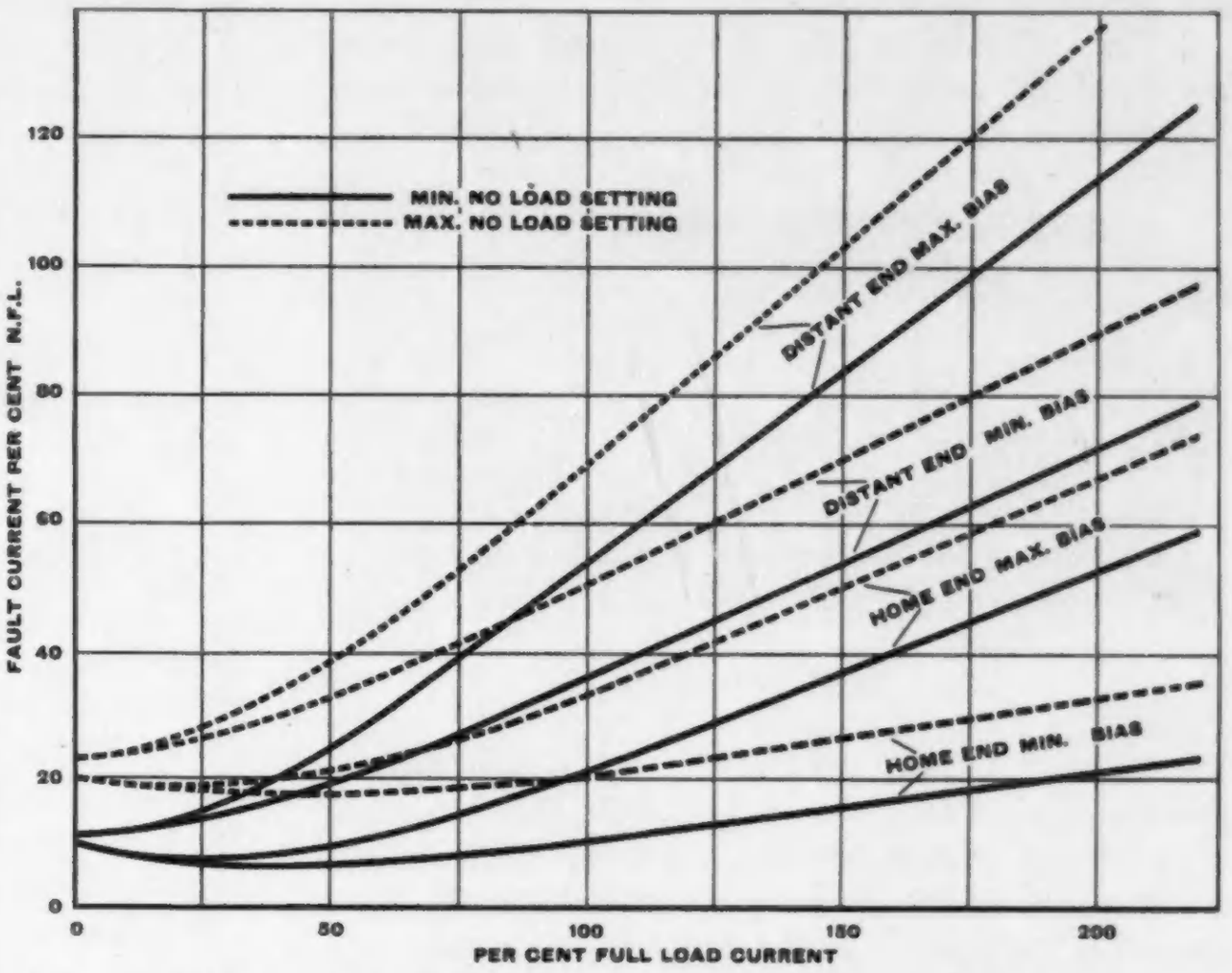
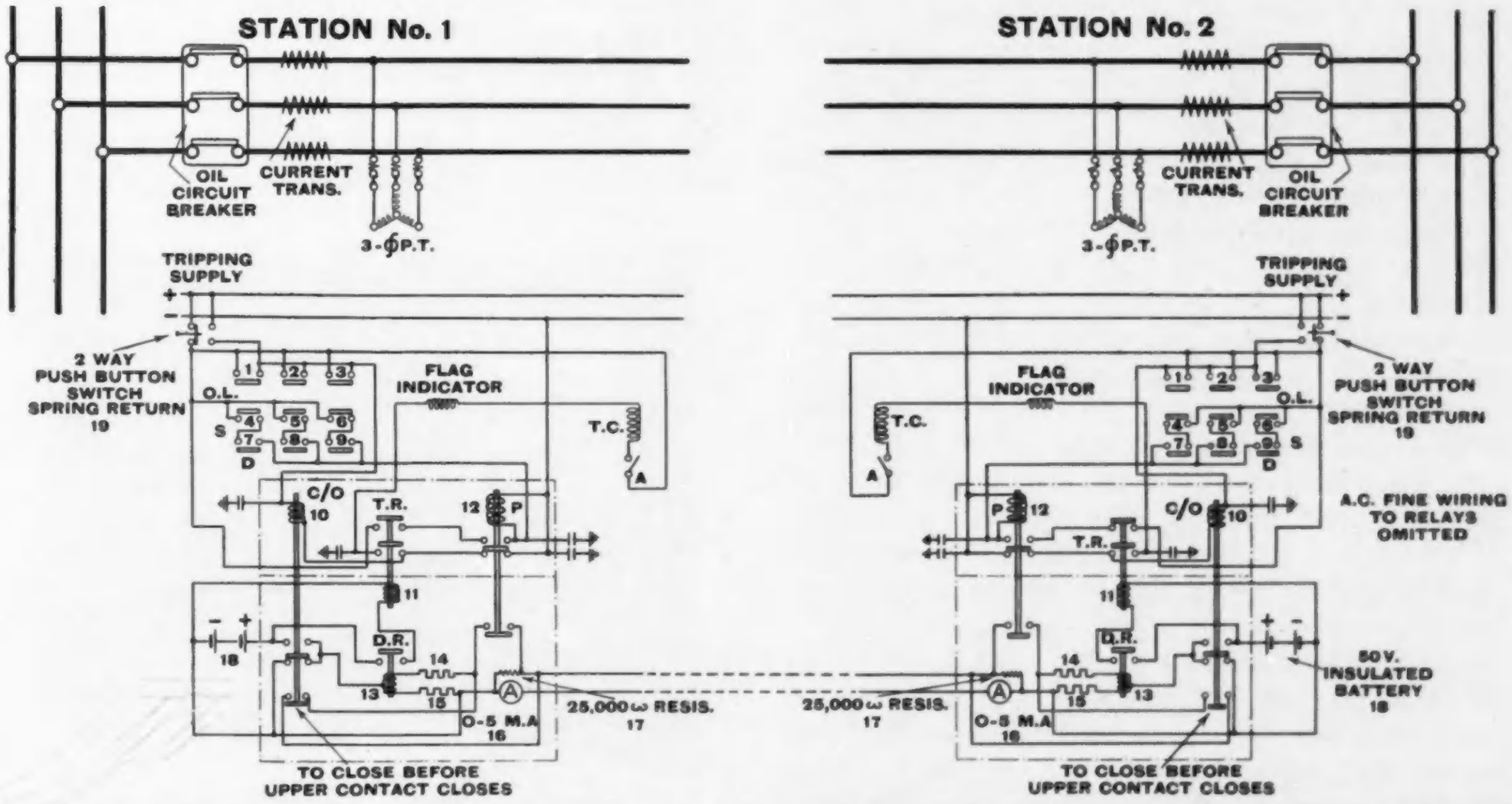


Fig. 11.—Characteristics of parallel feeder protection.



O.L.	Overload relay closes with 150% overload, after 0.1 sec. delay.	D	Directional relay closes with power flowing out of section; open at no power or with power flowing into section.	T	Trip coil.
S	Stabilising relay closes with 120% overload instantaneously.	P	Pilot short circuit relay.	A.	Auxiliary switch on oil Circuit Breaker.
				C.O.	Change over relay.
				T.R.	Trip relay.
				D.R.	Differential relay.

Fig. 12.—Diagram of connections of duplex protection as used on North West England area.

The present scheme depends for its operation upon the principle that when a heavy overload occurs, this overcurrent flows in and out of the sound sections, but flows into but not out of the faulty one. The latter condition is registered by the set of nine A.C. relay elements at the top of the network at each end, and a current is then sent over the pilot wire that causes tripping. It should be

noted that the upper six are all overcurrent elements, and will in general be replaced by three double-contact elements in future.

The D.C relays in the lower part of the diagram are provided either for the sending of the correct signal upon the duplex telegraphy principle, or for

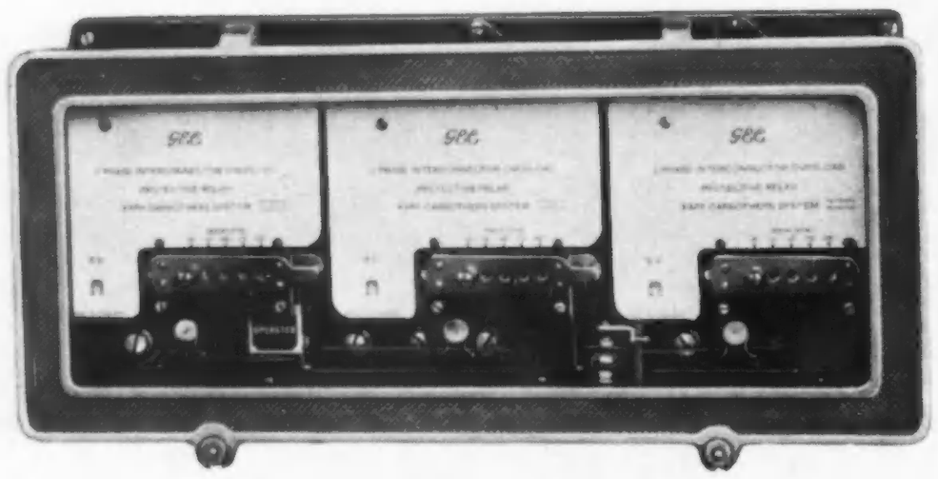


Fig. 13.—A.C. overload relays.

the isolation of any part of the equipment that is concerned with the power circuit from the telephone pilots, by an insulating link capable of withstanding a voltage of 15 kV. The relays with long insulated operating rods were added for this latter purpose.

The use of nine A.C elements, of which the bottom row of three are directional units, enables a signal to be sent that is infallibly correct under all conditions. In particular, the presence of the two overcurrent settings, differing by 25 per cent, obviates a risk of incorrect tripping to which other signal current schemes are liable. The error is due to an overload passing through a section, which has a value approximating to the setting of the over-current elements. Owing to the adjustment of these elements being slightly different, only that at one end functions, registering an internal fault when the feeder is actually sound.

As regards sensitivity, the left and right hand vertical sets of three A.C. elements at either end constitute directional overload arrangements associated with the red and blue phases respectively; and as the major current setting is 150 per cent, this value represents the sensitivity of the scheme for faults between phases. The middle set forms a directional earth leakage assembly with a setting of about 30 per cent, which therefore gives the sensitivity for faults to earth. The connections from the current and potential transformers are not inserted, since they are in accordance with the usual overload-and-leakage arrangement. The A.C. relay elements are all of the induction type, as shown in fig. 13, while fig. 14 illustrates the insulated rod and differential D.C. relays.

The pilot wire can be either permanently connected to the rest of the protective network, or, as in the present cases, connected only when an overload occurs. The latter method was used as it is just possible that a linesman may apply a testing voltage to a pilot by mistake, and thereby cause the relay to trip, if the connection is permanently made. In either case, the pilot can be used for telephony at the same time as for protection, but telephones have not been shown in the diagram as they are not used on the grid installations. They are, however, shown in fig. 2 of the article on "Signal Current Protection of Feeders" (*G.E.C. Journal*, Vol. III, No. 2, page 143).

The Duplex schemes have been in operation for some months, while other sections of the 66 kV grid are being similarly protected at the present time.

5. NEGATIVE PHASE SEQUENCE OR UNBALANCED PHASE SCHEME.

One of the most recent principles employed for protective gear is that based upon the flow of negative-phase-sequence current from a fault into the system. It should be explained that any unbalanced three-phase current may be resolved into three symmetrical components, that is, three sets of three equal currents which are either at the same phase angle, or are at 120° to each other and follow one another in regular phase sequence. Positive-phase-sequence current is alone present when the phases are balanced; negative-phase-sequence current is produced by a fault between phases, and has its phase rotation in the opposite direction to the original balanced current; and zero-phase-sequence current is the "residual" current flowing in a fault to earth.

Fig. 14.—Insulated rod D.C. relays.

The three kinds of current may be separated from one another by means of filters, which in the case of the first two consist of a bridge arrangement of resistances and reactances. Such filters are used to operate relays and thus detect the presence of negative-phase-sequence current. It is not an easy matter, however, to render such a scheme sensitive and stable at the same time, since its

correct functioning depends upon a very accurate balance between the values of resistance and reactance. Further, the method suffers from the usual defects of unbiassed schemes, in that the current transformers are apt to become themselves unbalanced at high overloads.

The G.E.C. negative-phase-sequence scheme, as installed in many parts of the South-West England grid, is based upon the error in balance existing between the currents in two phases when negative phase sequence current is present. Three biassed relay units are provided which directly compare the currents in the red and white, white and blue, and blue and red phases respectively, as shown by the diagram forming fig. 15. When one exceeds another by 10 per cent, the corresponding relay element trips and effects isolation.

Sensitivity is of great importance in this area, on account of the restriction of the fault currents by the comparatively high value of earthing resistors employed. At the same time the bushing current transformers have necessarily a very low VA capacity. Both of these considerations necessitated the greatest degree of sensitivity that could be achieved, and the relays, shown in fig. 15, were designed accordingly. They are constructed upon the disc and shaded-pole principle, the bias being adjustable and obtained by moving the pivot support of the disc.

The relays on the South-West grid are fitted with a D.C. kicking magnet to ensure the return of the disc to the "off" position following operation, a refinement that was rendered advisable on account of the special difficulties to which reference has been made. Like the last two schemes, this one has only been completed during the past few months, and is not yet in full operation pending the installation of an allied piece of equipment. Preliminary tests have, however, indicated that it will give the desired results.

The purpose for which this scheme has been applied is the isolation of the distant end of a feeder and transformer when the latter is located at a single-

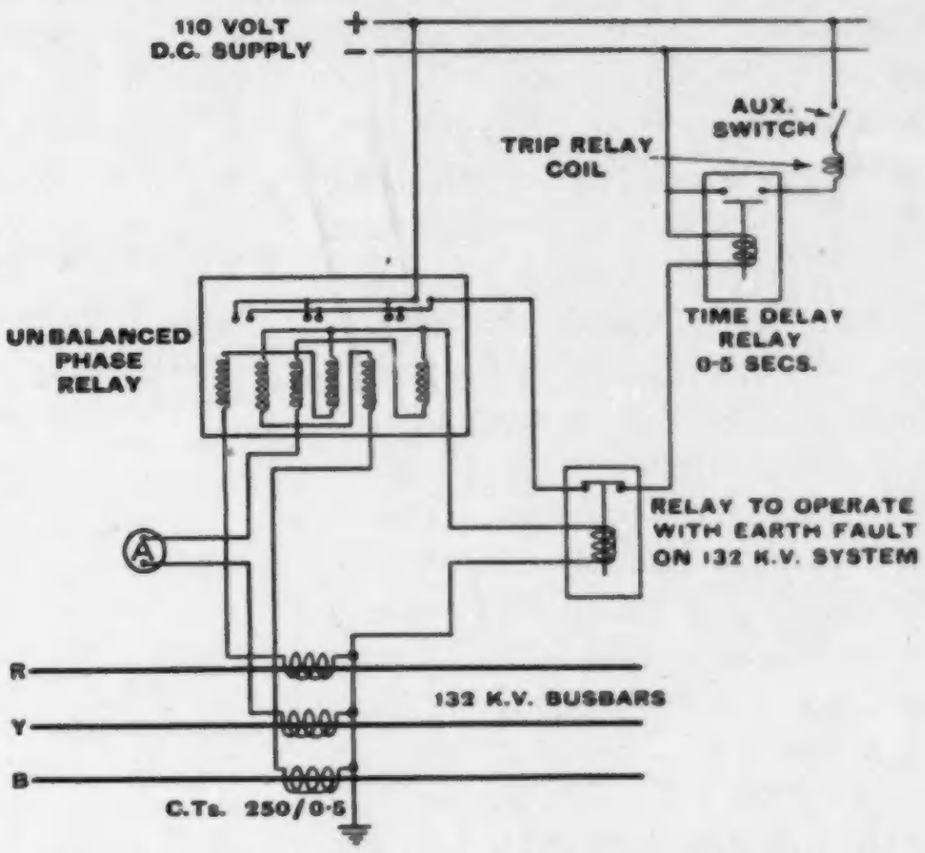


Fig. 15.—Unbalanced phase scheme used on South West England area.

switch station. The necessity for it is chiefly felt when a fault occurs on the secondary (low voltage) side of a transformer, which is readily isolated at this point by the transformer protective scheme. Since there is no circuit-breaker on the primary side, however, isolation has to be effected at the next station or substation, where the negative phase sequence scheme is installed.

The Communication and Supervisory Control System of the Grampian Electricity Supply Company.

By F. B. WILLIS,
G.E.C. Telephone Works.

Communication, protection and supervisory control systems for electric power networks have been discussed in the G.E.C. Journal in three previous articles. The first (vol. IV, No. 3, p. 165) dealt with the general requirements of a power system for such facilities, and the methods available for meeting these requirements, the second article (vol. V, No. 2, p. 115) showed the application of the methods to a typical urban and rural power system; while the third (vol. V, No. 3, p. 135) described the communication equipment for the Central England area of the grid.

The present article is devoted to the carrier current and supervisory equipment employed by the Grampian Electricity Supply Co. It is worthy of note that the scheme includes the first use of carrier current channels over E.H.T. power lines in Great Britain. Also, it is the first occasion upon which supervisory control has been effected by means of carrier current circuits.

ONE of the most interesting and extensive electric power supply systems in Great Britain is that owned and administered by the Grampian Electricity Supply Co. The original act governing the incorporation of the company came into force in 1922 and conferred wide powers for the generation and distribution of electricity in central Scotland, over an area of 4,214 sq. miles. This area has since been extended by some 5,000 sq. miles particularly in the Scottish Highlands. Perhaps the most outstanding feature of the undertaking lies in the fact that it provides an excellent example of the possibilities of generation by means of water power in Scotland. Some idea of the scope afforded the company for hydro-electric development may be gathered from the consideration of a few statistics.

The works so far constructed under the act of 1922 include about 284 square miles of catchment areas and the enlargement of two lochs to serve as reservoirs which are intended to collect and impound the water of a large number of rivers and streams. Up to the present time over 400 miles of overhead and underground transmission lines have been constructed.

The first hydro-electric station to be put into commission (Nov. 1930) was that situated on the shores of Loch Rannoch (fig. 1). Originally the capacity of the generating plant was 32,000 kW. More recently (Jan. 1st., 1934) a second hydro-electric station was brought into commission at Tummel Bridge, with an initial capacity of 34,000 kW.

The principal distribution point of the company's system is the Abernethy substation at which connection is also made to the Central Scotland section of the grid. Feeders from this substation radiate to Cupar, Leoch and Perth. That part of the system with which this article is concerned is shown in diagrammatic form at fig. 2.

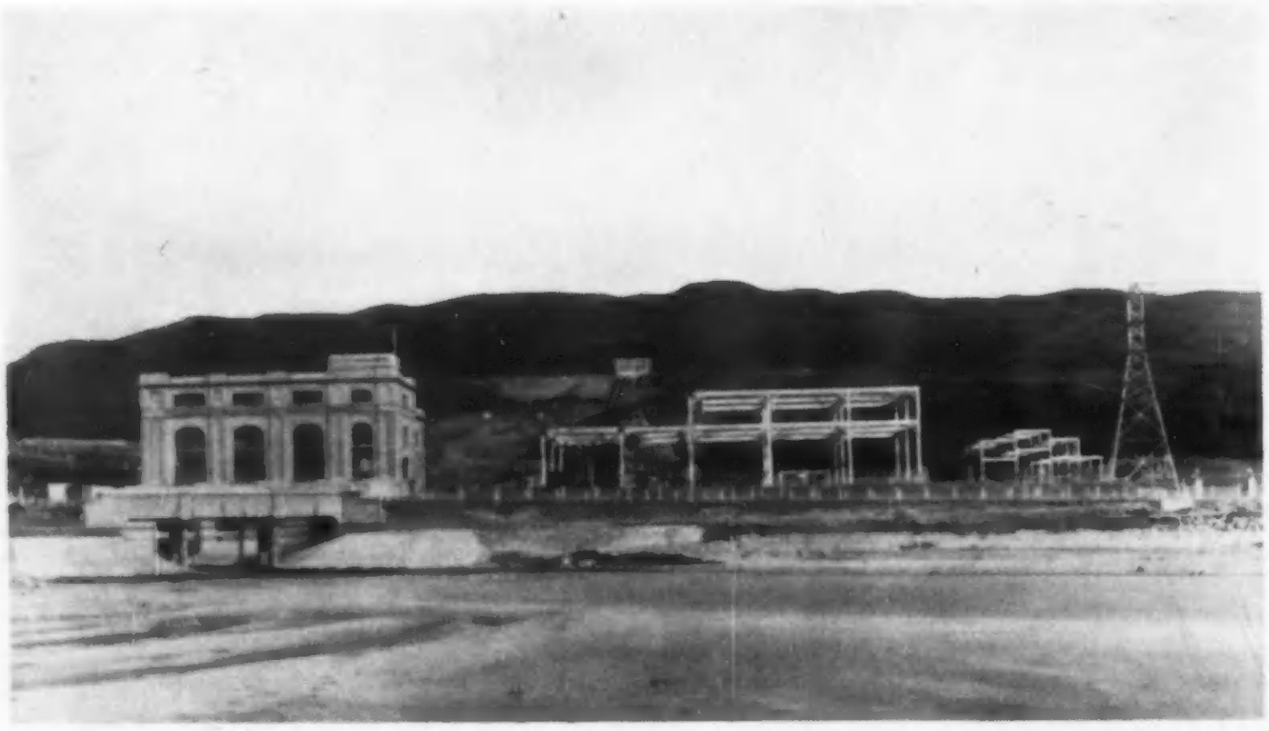


Fig. 1.—Rannoch Power Station and Switching Station as seen from Loch Rannoch.

It should be noted that both 132 kV and 33kV transmission lines are employed at various points of the system for the carrier current circuits. A view of the transmission line is shown in fig. 3.

It will be evident from the following description that the methods adopted for communication and supervisory control over the system are of a pioneering nature, and contribute in no small measure to the great interest which attaches to the plant and equipment installed in the area.

The first step was taken early in 1931 when a carrier current telephone channel superimposed

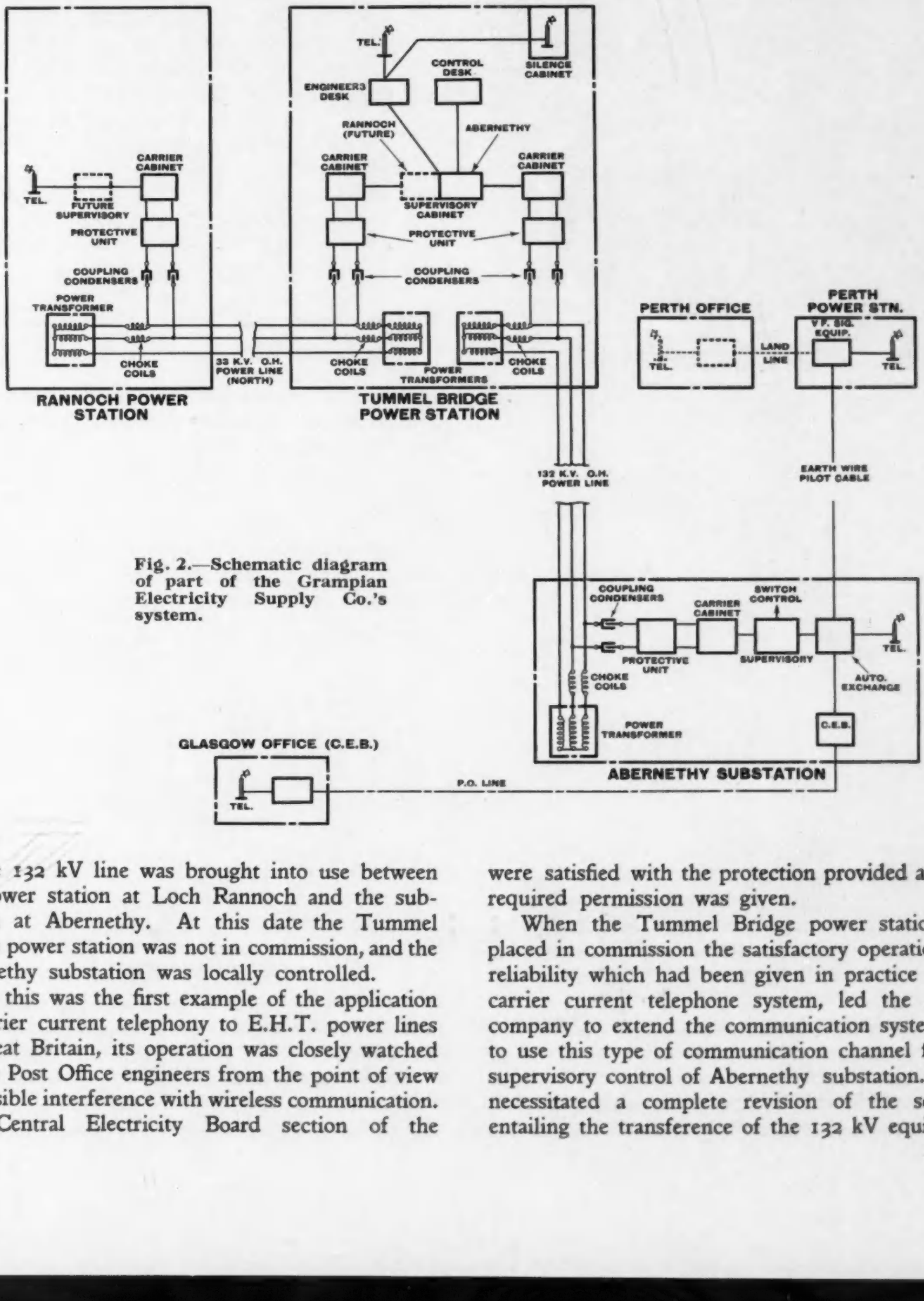


Fig. 2.—Schematic diagram of part of the Grampian Electricity Supply Co.'s system.

on the 132 kV line was brought into use between the power station at Loch Rannoch and the substation at Abernethy. At this date the Tummel Bridge power station was not in commission, and the Abernethy substation was locally controlled.

As this was the first example of the application of carrier current telephony to E.H.T. power lines in Great Britain, its operation was closely watched by the Post Office engineers from the point of view of possible interference with wireless communication. The Central Electricity Board section of the Abernethy substation is connected to the Board's Glasgow office by a telephone line rented from the Post Office, and it was obviously desirable that the control engineer at Rannoch should be able to communicate direct with the C.E.B. engineer at Glasgow without the delays which might be entailed in effecting a trunk call over the ordinary P.O. system. The Post Office were therefore approached with a view to connecting the carrier current channel to the C.E.B. rented line. This raised the question of possible danger to the department's equipment but after exhaustive tests the Post Office engineers were satisfied with the protection provided and the required permission was given.

When the Tummel Bridge power station was placed in commission the satisfactory operation and reliability which had been given in practice by the carrier current telephone system, led the supply company to extend the communication system and to use this type of communication channel for the supervisory control of Abernethy substation. This necessitated a complete revision of the scheme, entailing the transference of the 132 kV equipment

from Rannoch to Tummel Bridge and the provision of a new carrier current channel between these two points on the 33 kV line.

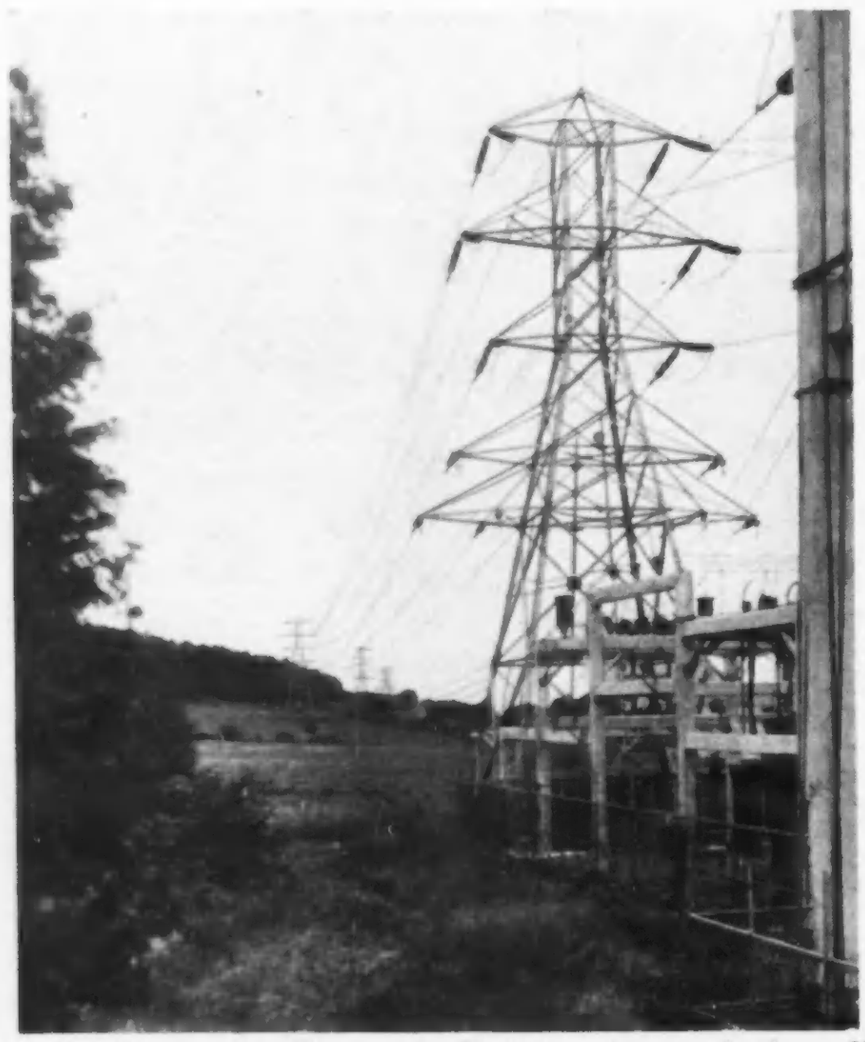


Fig. 3.—Rannoch—Tummel Bridge transmission line from Rannoch Switching Station. The towers carry two 132 kV and two 33 kV three-phase lines.

Fig. 4.—Double-circuit 33 kV transmission line from Abernethy to Perth, showing earth-wire pilot cable above the E.H.T. lines.

The scheme now comprises the following facilities, which are indicated at fig. 2.

(1) Carrier current telephony between Rannoch and Tummel Bridge over the 33 kV power line.

(2) Carrier current telephony and supervisory control between Tummel Bridge and Abernethy over the 132 kV power line.

(3) Telephone channel between Abernethy and the Perth power station through earth wire pilot cable erected on the 33 kV power line poles (fig. 4). This cable also provides two separate pilot circuits for the protection of the feeders, as well as acting as the earth wire.

(4) Connection of the supply company's telephone system to the C.E.B. line from Abernethy to the Board's Glasgow Office.

Provision has also been made for the following further facilities to be added at a later date :

(5) Conversion of Rannoch power station to supervisory control from Tummel Bridge over the existing carrier channel.

(6) Extension of the telephone line from the Perth power station to the administrative office of the supply company in Perth.

From the list of facilities given under items 1 to 4 above, it will be seen that the principal carrier current and supervisory equipments are situated at Rannoch power station, Tummel Bridge power station and Abernethy substation.

Telephony is effected by modulating the carrier frequency in an exactly similar manner to wireless telephony, and in fact the system is essentially a wireless telephone system, the power line taking the place of the medium between the aerials (this accounting for the use of the term "wired wireless," which is sometimes employed.)

The supervisory control signals are effected by means of trains of impulses obtained by interrupting the carrier frequency as explained later. A special arrangement of tuned circuits in the receiving set causes speech to pass through a speech amplifier

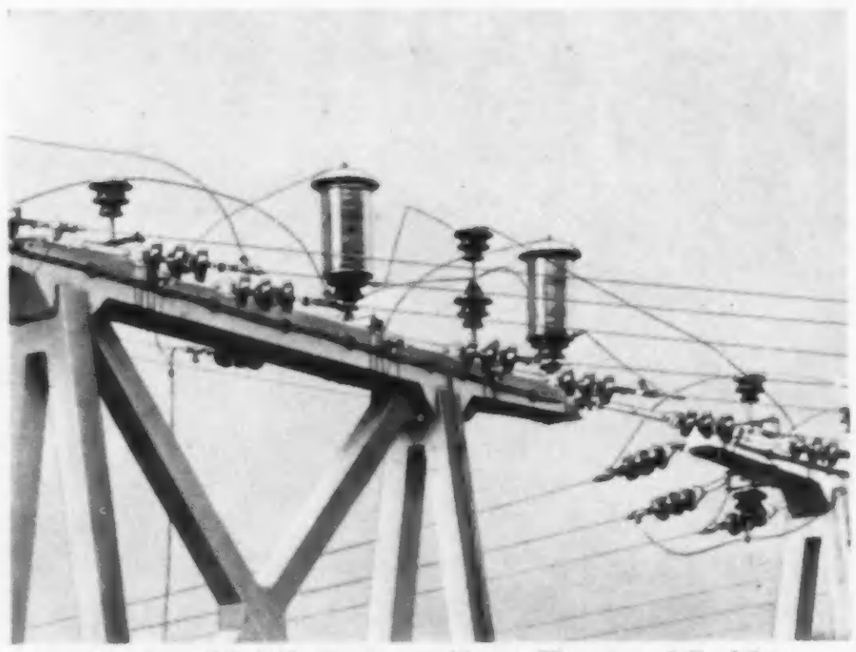


Fig. 5.—33 kV choke coils at Tummel Bridge Switching Station.

to the telephone whereas, the control signal impulses pass separately to the supervisory apparatus.

Before proceeding to a description of the principal items of apparatus, it will prove convenient to give a list of these at each station which may be read in conjunction with fig. 2.

RANNOCH POWER STATION.

2—33 kV choke coils.
2—33 kV coupling condensers.

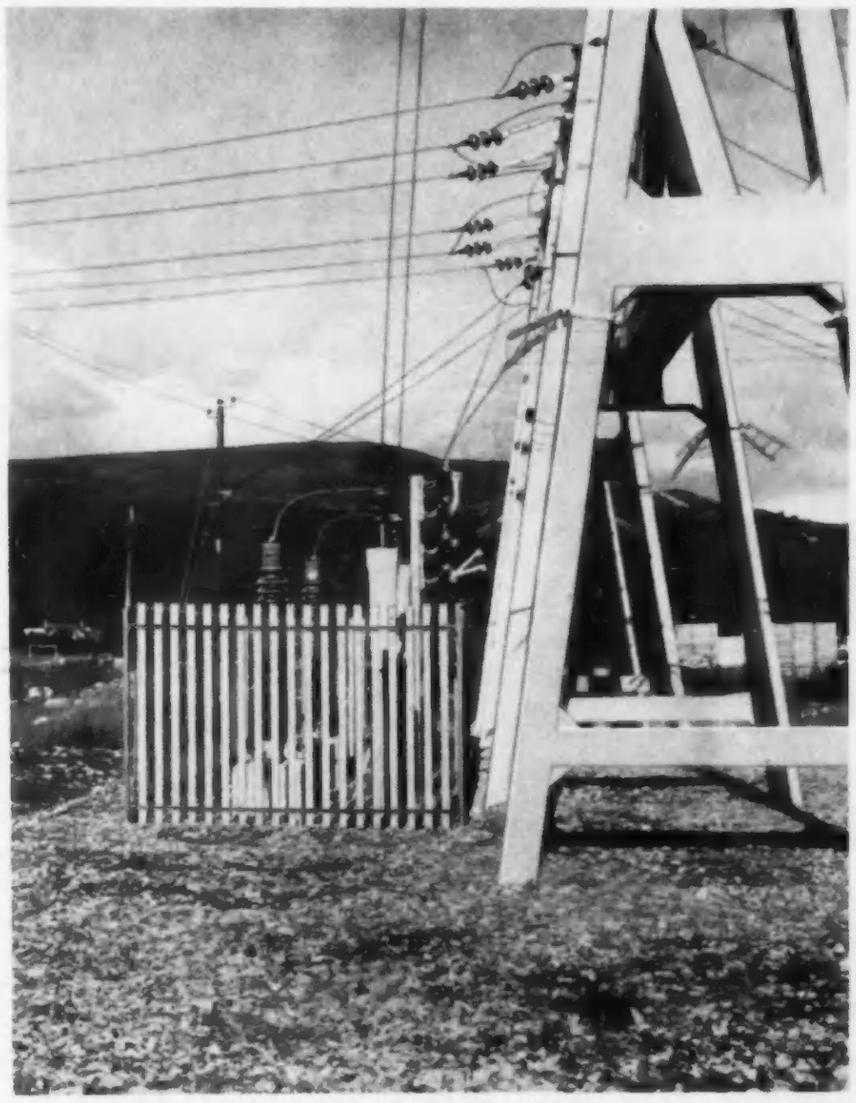


Fig. 6.—33 kV coupling condensers in enclosure at Tummel Bridge Switching Station.

1—Protective unit.
1—Carrier cabinet.
1—Auxiliary relay box.
1—Power board to control battery supplies.

TUMMEL BRIDGE POWER STATION.

2—33 kV choke coils.
2—132 kV choke coils.
2—33 kV coupling condensers.
2—132 kV coupling condensers.
2—Protective units.
2—Carrier cabinets.
1—Supervisory cabinet.
1—Power board to control battery supplies.
1—Engineer's desk.
1—Control desk.

ABERNETHY SUBSTATION.

2—132 kV choke coils.
2—132 kV coupling condensers.
1—Protective unit.
1—Carrier cabinet.
1—Supervisory cabinet, which includes a small automatic telephone exchange.
1—Power board to control battery supplies.

Reference to fig. 2 will show the general arrangement of the circuits. The chokes, fig. 5, and coupling condensers, fig. 6, are in all cases connected directly to the power lines at their terminations. From the coupling condensers the circuit passes via the protective unit (which safeguards the personnel and apparatus) to the carrier cabinet and hence to the telephone and supervisory apparatus.

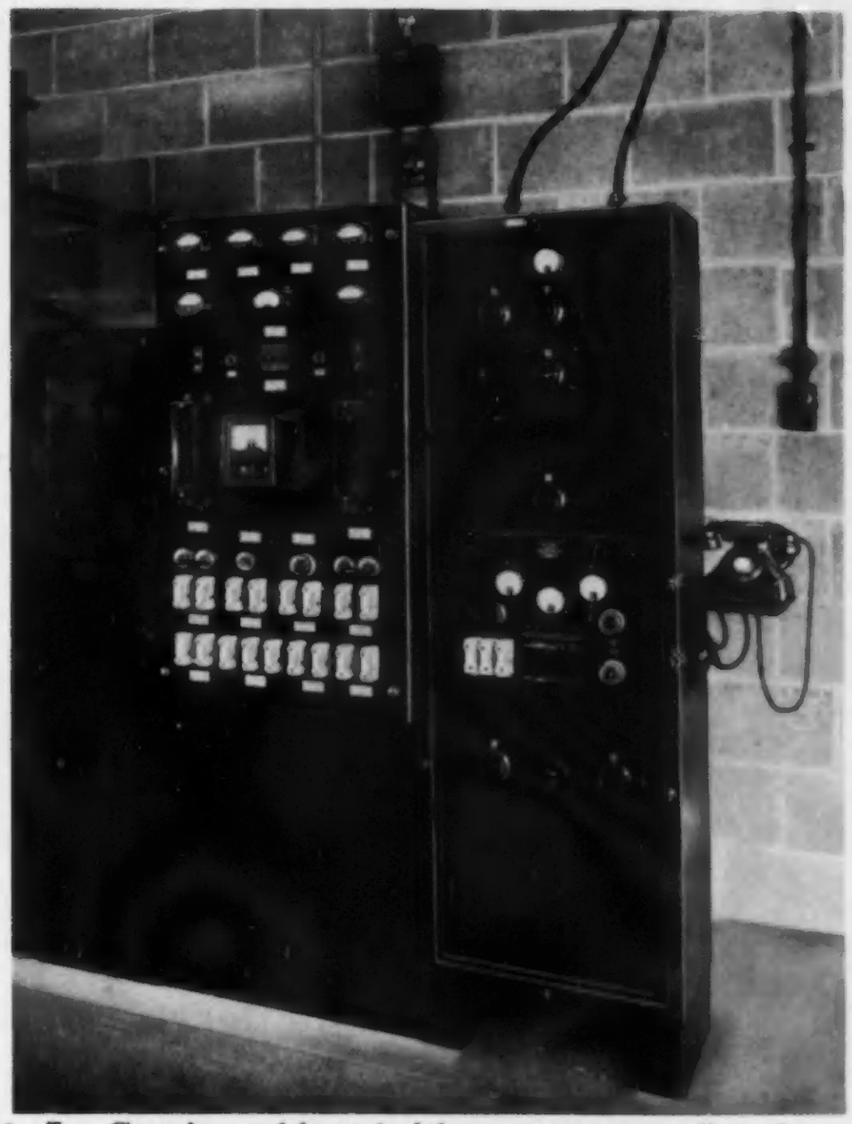


Fig. 7.—Carrier cabinet (with cover removed) and power board at Rannoch. The auxiliary relay box can be seen on the wall above.

Fig. 8.—Tummel Bridge Power Station; view from Tummel Bridge.

The locations of the various items differ at the three stations. Fig. 7 is a view of the equipment on the control floor at Rannoch power station and shows the carrier cabinet, the auxiliary

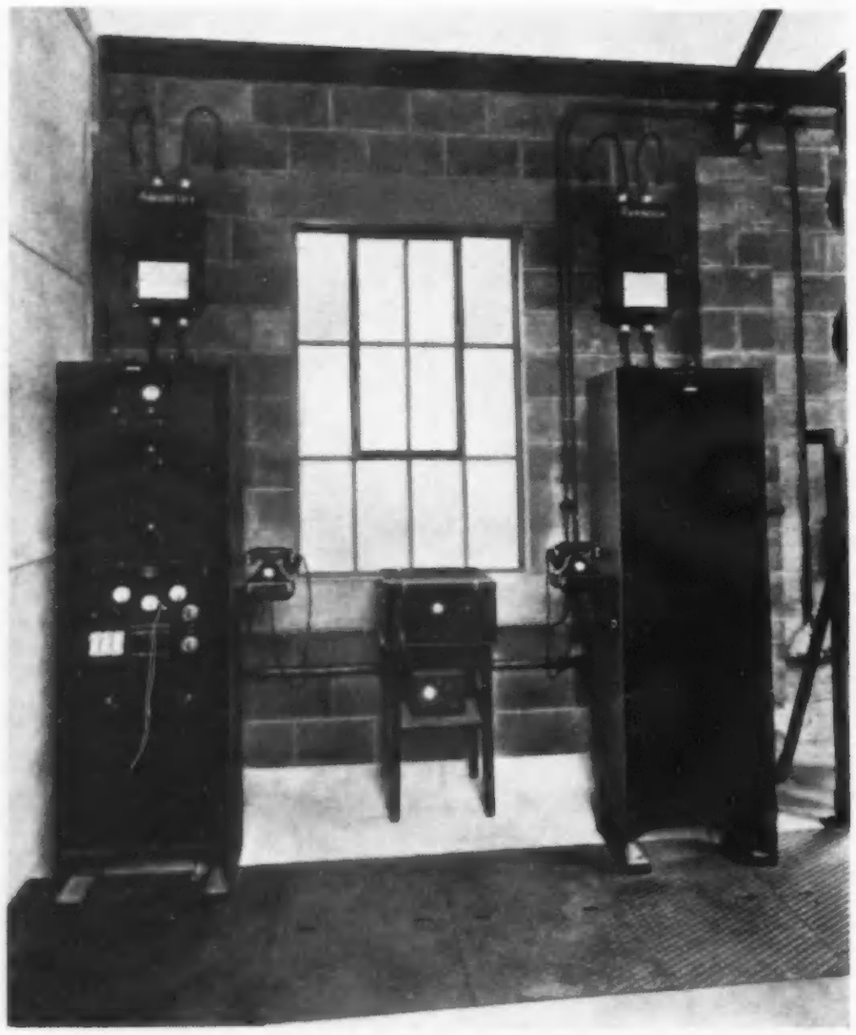


Fig. 9.—Carrier cabinets and protective units (above) in control hut at Tummel Bridge Switching Station.

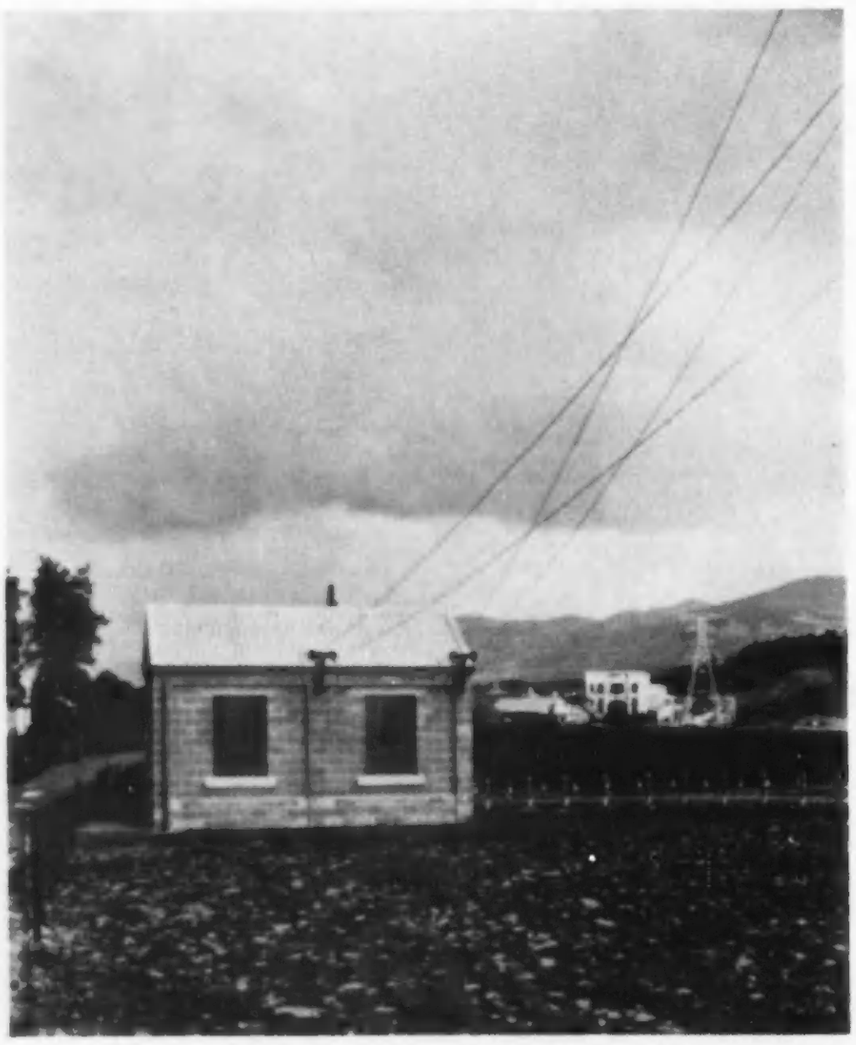


Fig. 10.—Control hut at Tummel Bridge Switching Station, showing method of leading in carrier circuits from the coupling condensers. Power station in the background.

relay box which contains the relays in connection with the signalling arrangements, and the power board for the supplies to the carrier set.

At Tummel Bridge, a general view of which is shown in fig. 8, the protective units and carrier cabinets are housed in the Switching Station control hut, fig. 10, which can be seen also to the right of fig. 11. From the carrier sets in this hut the circuits are taken by underground multicore cables to the power house, where the telephone circuits pass to the engineer's desk, seen to the left of fig. 12, and the signalling circuits to the supervisory cabinet fig. 13. There are two telephones on the engineer's desk and an extension from the desk connects to a telephone in a silence cabinet. The supervisory cabinet is connected by multicore cable to the control desk, which can be seen to the right of the engineer's desk in fig. 12.

At Abernethy substation the protective unit and carrier cabinet is housed in a small hut, together with the battery supplies. A small automatic telephone exchange is located in the supervisory cabinet in the auxiliary plant house. The lines from the carrier set, from the telephone in the Abernethy local control room, from the Perth power station and from the C.E.B. connection are taken to this automatic exchange. Fig. 15 shows a view of the supervisory cabinet, which is connected by multicore cables to the various equipments which are controlled, indicated and metered.

The automatic exchange at Abernethy provides a complete system of intercommunication between the various offices by dialling or the operation of keys. Rannoch power station is not normally connected to this exchange, however, but can be connected when necessary by means of a key on the engineer's desk at Tummel Bridge.

Having discussed the general layout of the scheme, it remains to describe in greater detail the facilities provided and the operation of the equipment.

SUPERVISORY EQUIPMENT.

The control desk at Tummel Bridge consists of a sloping panel which contains a mimic diagram (fig. 16), of the power connections at Abernethy substation. This diagram includes coloured lamps to show the positions (open or closed) of the oil switches, with selector keys for their remote operation, and mechanical indicators which can be set by hand to show the positions (open or closed) of the air-break isolators. Also mounted on the panel are four voltmeters, four ammeters, and a voltage booster tap indicator, with keys for operating them.

The equipment at present provides the following operations :

(1) Controls the opening and closing of 9 oil switches.
(2) Indicates continuously the position (open or closed) of these 9 oil switches.
(3) Controls a 15-point voltage booster tapping switch.
(4) Indicates the position of the voltage booster tapping switch.

(5) Indicates on demand the current or voltage or either of two 33 kV bus-bars.
(6) Indicates on demand the current or voltage of either of two 132 kV feeders.

Provision has also been made for the addition at a later date of a second voltage booster, and of 8 ammeters for the 33 kV feeders.

All the operations are carried out by trains of impulses in a similar manner to an automatic exchange, and the apparatus therefore comprises standard relays and selectors. To obviate false operation due to loss of an impulse or through any other cause, the G.E.C. check-back system is employed. This prevents the carrying out of an operation until the selecting mechanism at the receiving end has sent a corresponding signal back to the sending end. This signal is then automatically compared to the originating signal, and if they are the same a visual indication is given and a relay functions to allow the operation to take place.

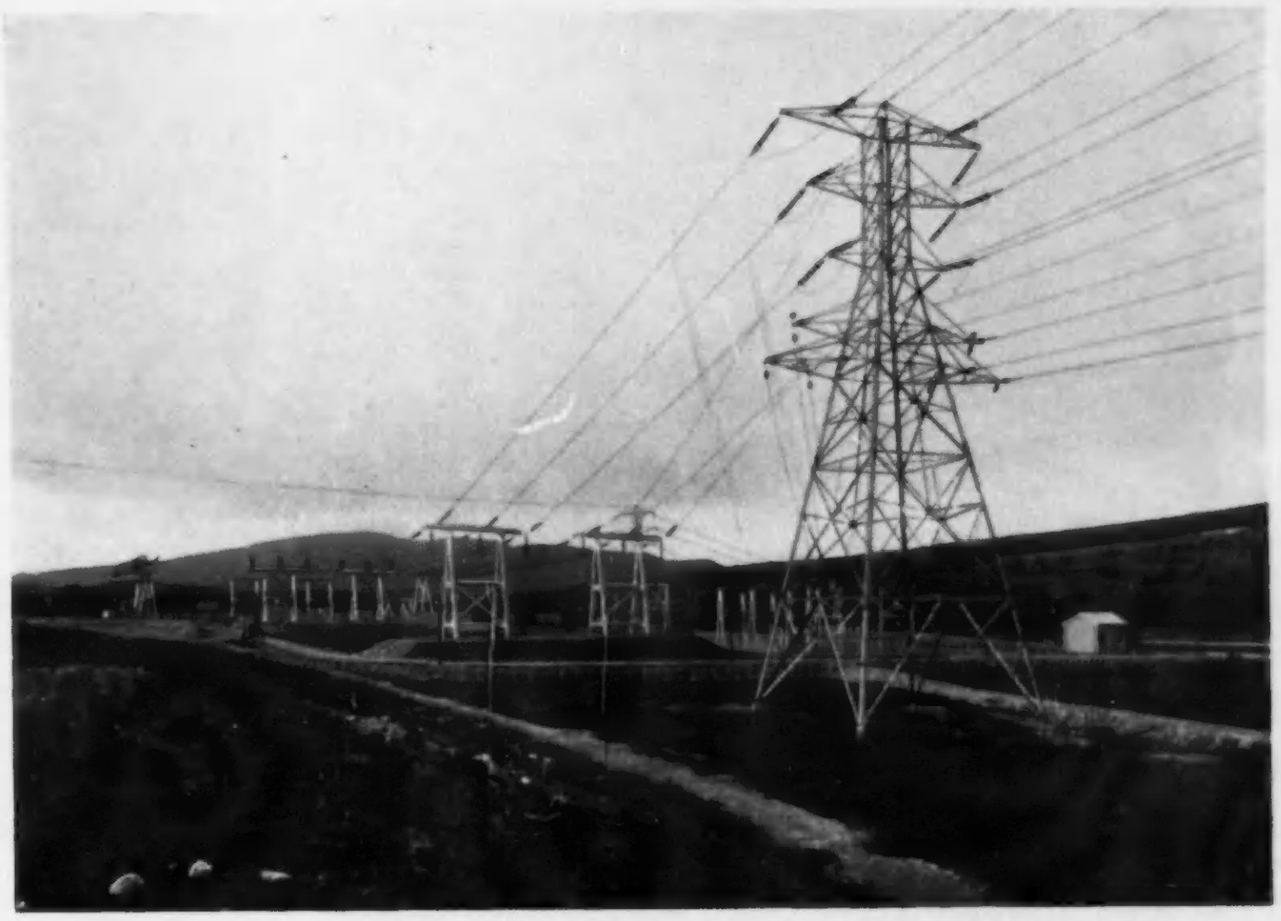


Fig. 11.—Tummel Bridge Switching Station showing to the right hut in which carrier sets are installed.

The operation of this equipment may be illustrated by considering the case of an oil switch at Abernethy which is in the open position. At the position on the mimic diagram corresponding to this oil switch is a four-position selector key, the four positions being (1) "Open Select" (2) "Open Indicate" (3) "Close Indicate" and (4) "Close Select." Above this key are three lamps coloured green, white and red respectively. With the switch in the open position, the green lamp will be glowing and the key in the position "Open Indicate." In order to close the oil switch the control engineer turns the key to the position "Close Select." The supervisory apparatus then operates at each end and prepares the circuits for this operation. As soon as the circuit is correctly prepared, the check-back signal from the other end causes the white lamp to glow, thus indicating to the engineer that the operation can be performed. To carry out the operation he now depresses a separate operating key (which is common to all operations). As soon as the operation is correctly performed, the green lamp is extinguished and the red lamp glows. The selector switch is then turned to the position "Close Indicate," which causes the white lamp to be extinguished.

Should the oil switch open due to overload or any other cause, the lamps change over from red to green, the white lamp glows, and an alarm bell rings, the alarm bell giving warning that an uncontrolled operation has taken place, and the white lamp indicating the particular apparatus affected. A key is provided to silence the alarm bell, and the white lamp can then be extinguished by turning the selector key either to "Open Indicate," if it is desired to leave the switch open, or to "Close Select," if it is desired to reclose it.

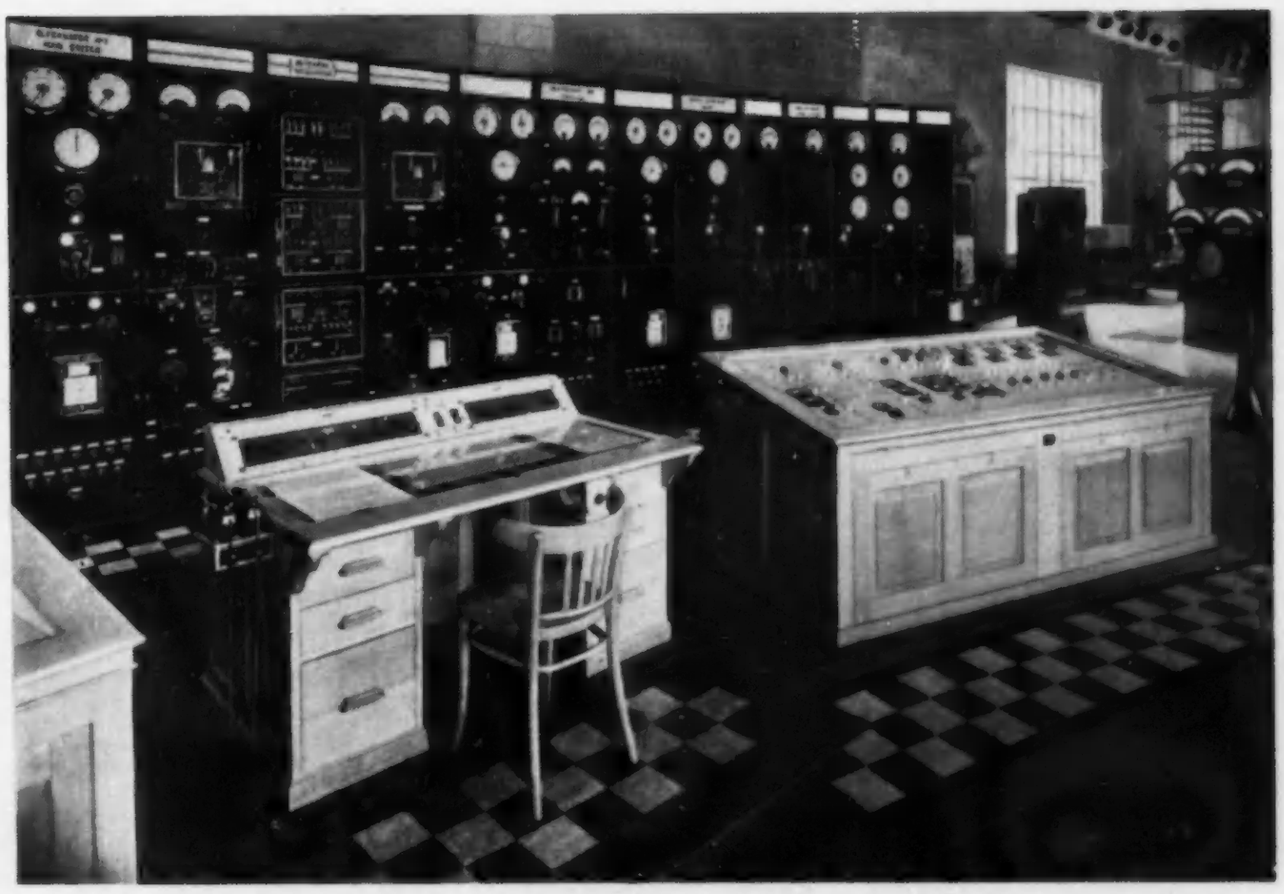


Fig. 12.—Engineer's desk (left) and control desk (right) at Tummel Bridge Power Station.

The white lamp therefore serves the following functions:

(1) It indicates when an operating circuit is correctly prepared.
(2) It indicates that an uncontrolled operation has taken place.

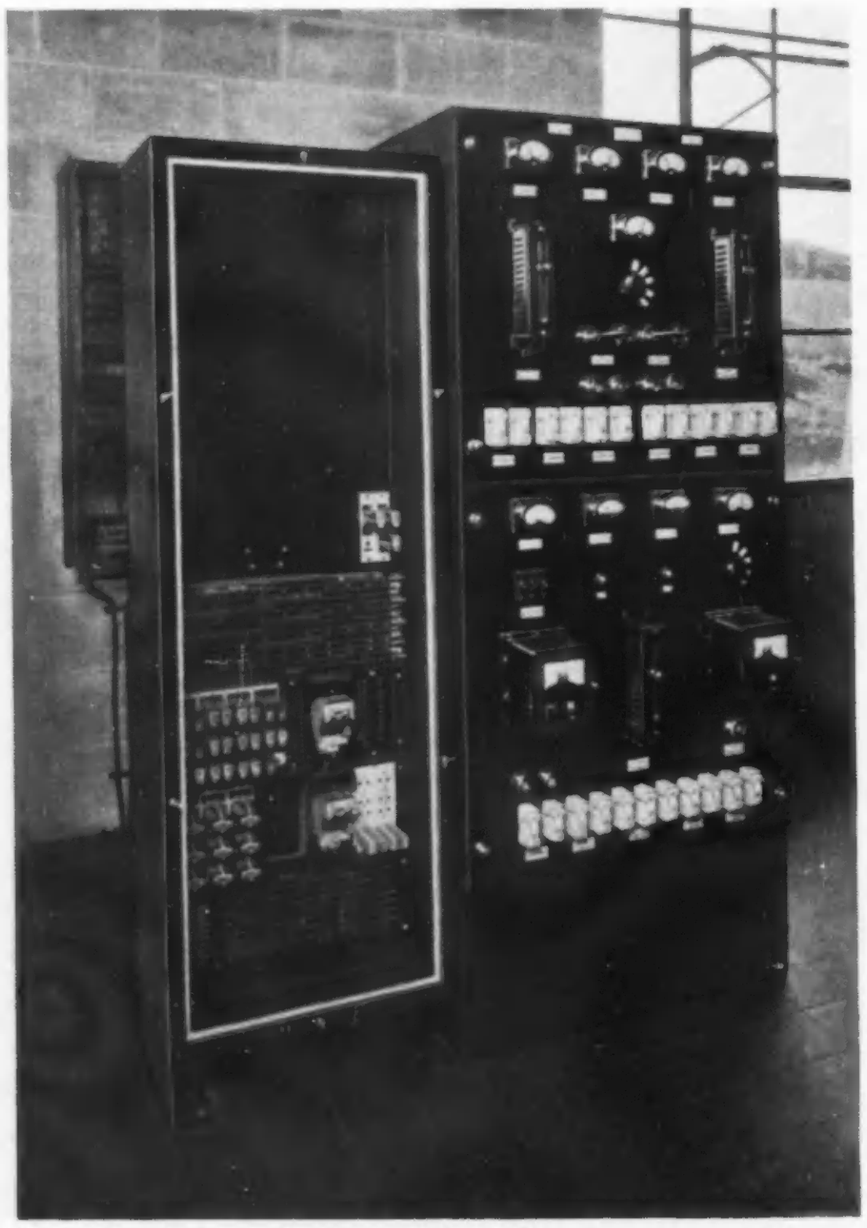


Fig. 13.—Supervisory cabinet (cover removed) and double circuit power board at Tummel Bridge Power Station.

white lamp will glow. As the white lamp is only alight for occasional short periods, it is far less likely to burn out than the red or green lamps, one of which is always alight.

The metering indications are transmitted by converting the meter reading at Abernethy to a number of impulses proportional to the meter reading. These impulses cause the arm of a variable potentiometer at Tummel Bridge to step round, which injects into the meter on the desk a voltage proportional to the number of impulses. This conversion is effected by a special meter at Abernethy, fig. 17. The meter element is of standard construction, and the moving part is of the usual light construction in order to obtain sensitivity. The pointer, however, instead of moving over an indicating scale, moves immediately above, though not in contact with, a series of contacts. When the corresponding key at Tummel Bridge is operated it causes a bar to be depressed in the meter at Abernethy which presses the pointer down on to one of the contacts, and according to the position of this contact in the series, a corresponding number of impulses is transmitted back to Tummel Bridge.

The supervisory apparatus is so designed that should a supervisory or indicating signal be initiated while a telephone conversation is taking place over the carrier circuit, it takes priority and interrupts the telephone conversation. Arrangements are also provided to give telephone priority to certain selected stations, which enables them to cut in on telephone connections between other stations.

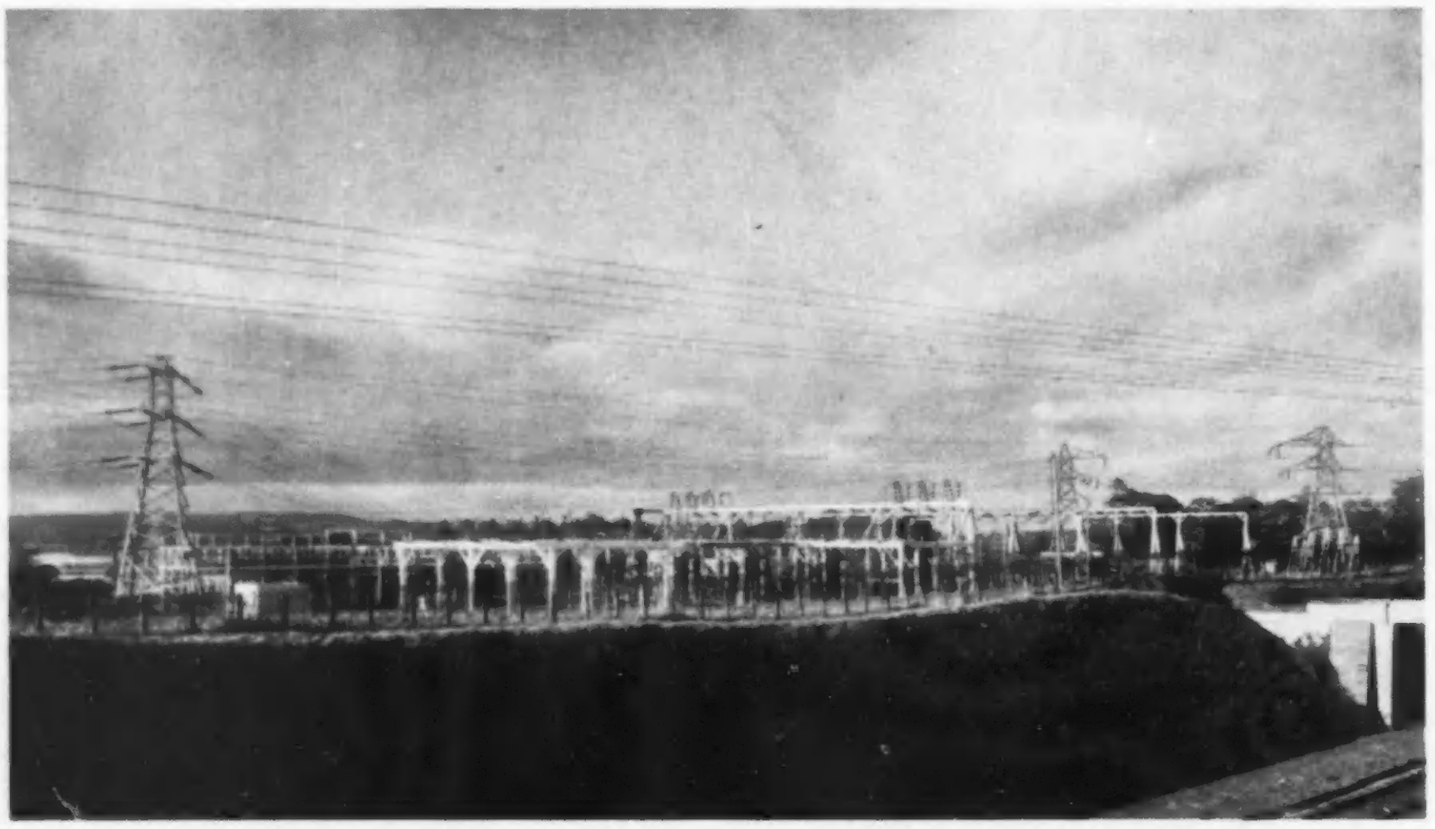


Fig. 14.—Abernethy Sub station.

(3) Should either of the red or green lamps burn out, it enables the position of the oil switch to be ascertained, since, if the selector key is turned to the "Indicate" position opposite to the position of the oil switch, the

On the telephone circuits ringing is effected by means of the supervisory apparatus, the ringing signal being one of the points on the selector switches in the supervisory cabinets. In the case of the Rannoch–Tummel circuit, which at present

has no supervisory equipment, an auxiliary relay box, previously mentioned, is provided at Rannoch which contains the necessary automatic apparatus to effect the signalling operations. Similar equipment is provided at Tummel Bridge, being located in the part of the supervisory cabinet allocated to the Rannoch circuit.

CARRIER EQUIPMENT.

At the end of each section choke coils are connected in the power line to prevent the carrier frequency from passing to the power transformers. From the line side of the choke coils, connections are taken through coupling condensers to the protective unit and hence to the carrier cabinet. The coupling condensers are insulated for the full voltage of the power line, and while transmitting the carrier frequency, they prevent any power frequency currents from flowing into the carrier equipment. In the case of the 33 kV line they are mounted on post type insulators, fig. 6, while in the case of the 132 kV line they are of the suspension type. The protective unit consists of fuses and low voltage spark gaps, which isolate the carrier cabinet in the unlikely case of failure of the insulation in the coupling condensers.

The carrier cabinets, fig. 9, consist of double sheet steel structures with a locked cover back and front. The sections of the equipment are made up on individual panels, each of which can be disconnected and removed separately without disturbing the remainder, thus facilitating inspection.

(2) The line tuning panel, which contains the variable condensers and tapped inductances for tuning the line to the carrier frequencies, and a milliammeter and key for measuring the output to the line.

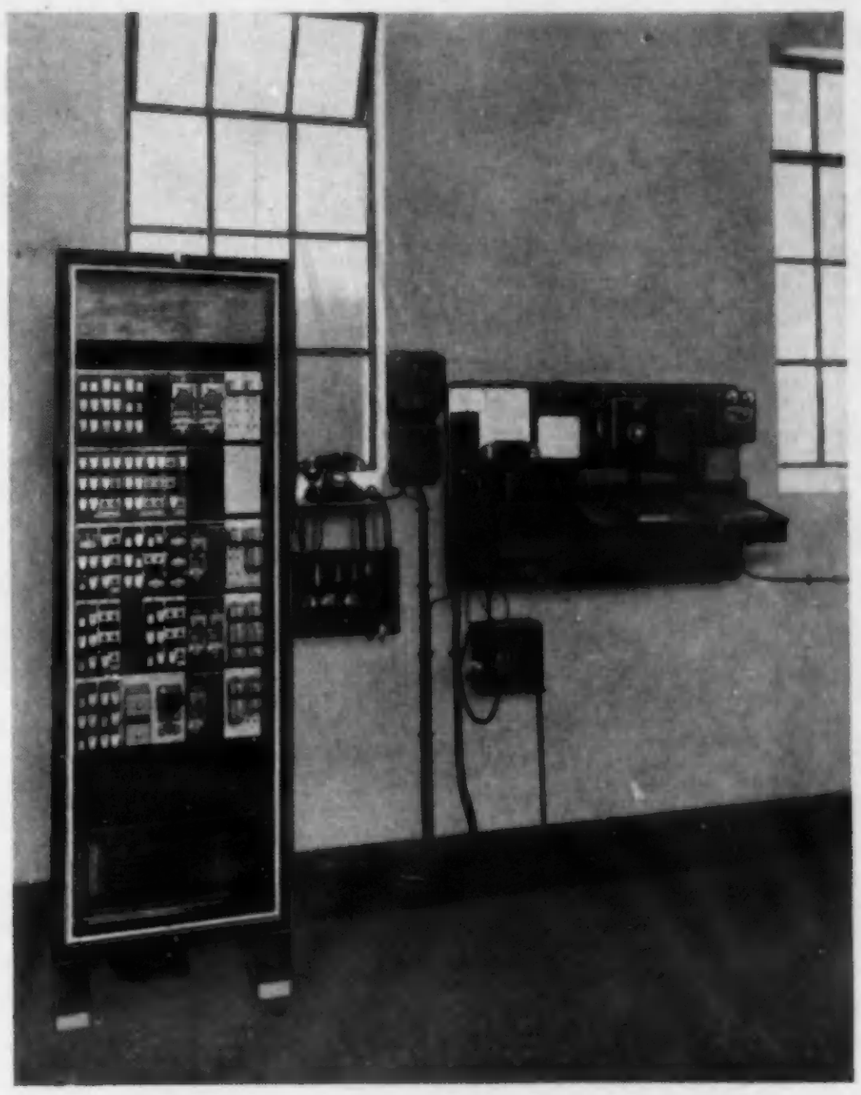


Fig. 15.—Supervisory cabinet (cover removed) at Abernethy Substation.

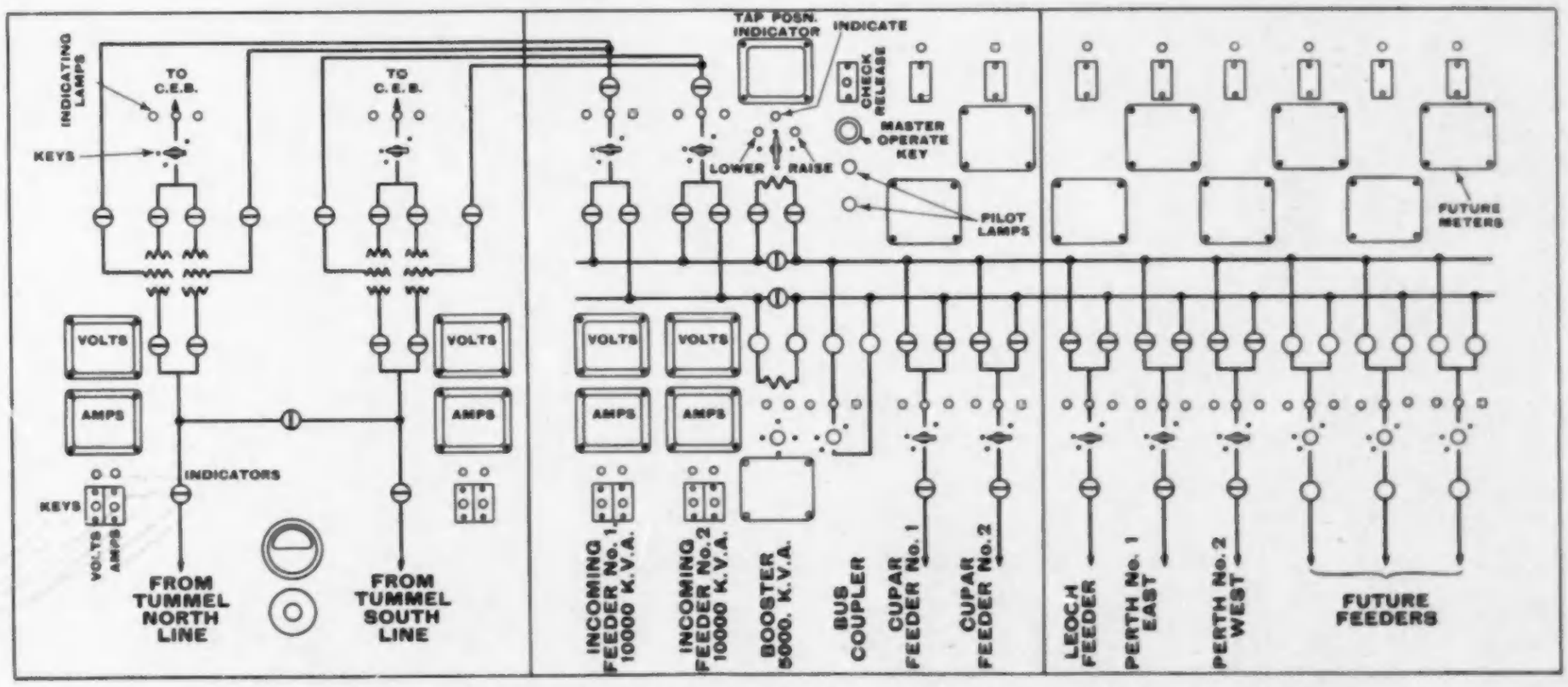


Fig. 16.—Mimic diagram on control desk at Tummel Bridge Power Station.

The apparatus is arranged in the following order, starting at the top:

(1) The incoming line from the protective unit comes in through two bushings on the top of the cabinet.

(3) The oscillator panel, which generates the carrier frequency appropriate to the station.

(4) The modulator panel, where the carrier frequency is modulated by the speech frequency. This panel also contains a speech amplifier.

(5) Miscellaneous apparatus panel. This contains the switches and fuses for the power supplies, meters and keys for measuring voltages and currents in different parts of the equipment, alarm lamps and other miscellaneous apparatus. One alarm lamp is provided in association with each valve in the equipment. Should the anode current of any valve fail for any reason, a relay causes the associated alarm lamp to glow, and also rings an alarm bell mounted in the power house or sub-station.

Fig. 17.—Transmitting meter as used at Abernethy substation, showing contact bank.

(6) The demodulator panel, in which the modulated carrier current is rectified and which also includes speech and signal amplifiers.
(7) The filter panel, or a 2-wire 4-wire panel, the functions of which are explained below.
(8) All battery supplies, alarm, telephone and signalling circuits, etc., are taken to a terminal strip at the bottom of the cabinet.

A separate carrier frequency is provided for communication in each direction, both frequencies being superimposed on the same pair of power lines. This corresponds to 4-wire working in ordinary telephony, in which one pair of wires is used for speech in one direction, and a second pair for speech in the other direction. At Rannoch and Tummel Bridge this 4-wire connection is maintained up to the telephones, but at Abernethy the 4-wire circuit is converted to a 2-wire circuit in the 2-wire 4-wire panel by means of a "mixing" transformer and balance network. This is necessary since it has to connect, *via* the automatic exchange, to the earthwire pilot cable and P.O. line, which are 2-wire circuits.

The two carrier frequencies between Rannoch and Tummel Bridge are 94 and 150 kilocycles per second, and between Tummel Bridge and Abernethy they are 81 and 130.5 kilocycles per second.

An explanatory diagram of the equipment in the carrier cabinet is given at fig. 18. The incoming speech first passes through the speech amplifier and then to the modulator, where it meets the carrier frequency provided by the oscillator. The carrier and both side bands produced in the modulator then pass to the line *via* the line tuning panel, which consists of the necessary condensers and inductances to tune the line to the carrier frequency, and so reduce reflection losses. Since the channel works on different frequencies in the two directions, the tuning is arranged so that the circuit resonates at both frequencies.

The modulated carrier frequency transmitted from the other end of the line passes *via* the line tuning panel to the demodulator where it is rectified and passed on to the speech amplifier. From here it passes through a low-pass filter to the telephone. The object of the filter is to eliminate the hissing noise caused by the high voltage on the power line and to suppress any heterodyne whistles caused by external interference. At Abernethy both outgoing and incoming speech pass through the 2-wire 4-wire panel, and in this case the filter is not required, since the "mixing" transformer acts as a filter.

The method of signalling and impulsing is based upon the following operations. The oscillator generates continuously the carrier frequency allocated to the station, but this cannot pass to the line from the modulator until a relay on the modulator panel is energised. This relay is operated when "positive" is applied to the "Send Signal No. 1" wire (see fig. 18), which is effected by a relay in the supervisory cabinet (or relay box where no supervisory cabinet is fitted). This latter relay is energised when "positive" is applied to the "Receive Signal No. 1" wire, which is effected only when and as long as the carrier frequency is being received from the other end of the line.

Exactly the same conditions apply at the station at the other end. It will be seen, therefore, that the two carrier frequencies are normally transmitted continuously, one in each direction, and that the transmission of each frequency depends on the correct receipt of the other frequency. Thus, should failure of either frequency occur for any reason, the other frequency is also caused to fail (after a predetermined time), and an audible alarm is given at both ends. The initiation of the transmission is allowed for by making provision for temporarily operating the relays by other means.

Signal No. 2 is sent when "positive" is applied to the "Send Signal No. 2" wire. The effect of this is to interrupt the operation of the oscillator at regular intervals, so that the carrier frequency "makes" and "breaks" at a frequency of interruption of about 70 cycles per second. At the receiving end, this interrupted carrier frequency causes "positive" to be removed from the "Receive Signal No. 1" wire and applied to the "Receive Signal No. 2" wire. The relay in the supervisory

cabinet previously referred to is also held closed by the receipt of Signal No. 2, so that the transmission of the outgoing carrier frequency is not stopped.

The operation of the supervisory signals consists of a combination of Signal No. 1 and Signal No. 2 in the following manner. The initiation of a supervisory signal from the control desk causes Signal No. 2 to be sent, which, as described above, transfers "positive" from the "Receive Signal No. 1" wire to the "Receive Signal No. 2" wire. This causes the supervisory apparatus to prepare the circuit for stepping the selector switch. At the sending end, the supervisory equipment now interrupts Signal No. 2 (and therefore reinstitutes Signal No. 1) a number of times corresponding to the number allocated to the operation to be performed, and this causes the selector switch at the receiving end to step the same number of contacts. After this train of impulses, Signal No. 2 is maintained until the "operate" key is depressed. This causes the carrier frequency to be cut off altogether for a definite short period and removes "positive" from both Signal No. 1 and Signal No. 2, which sets up a further combination at the receiving end to prepare the "operate" circuit. (The length of this interruption to both signals is insufficient to cause the failure of the outgoing carrier previously described). At the end of the period, interrupted carrier frequency is again transmitted, which therefore operates Signal No. 2. This re-application of Signal No. 2 after a complete interruption of both signals, is the "operate" signal. As soon as the engineer at the control desk receives the signal indicating that the operation has been performed, he moves the selector key to the corresponding "Indicate" position, and this causes further impulsing to take place which steps the selector switch back to the "zero" position.

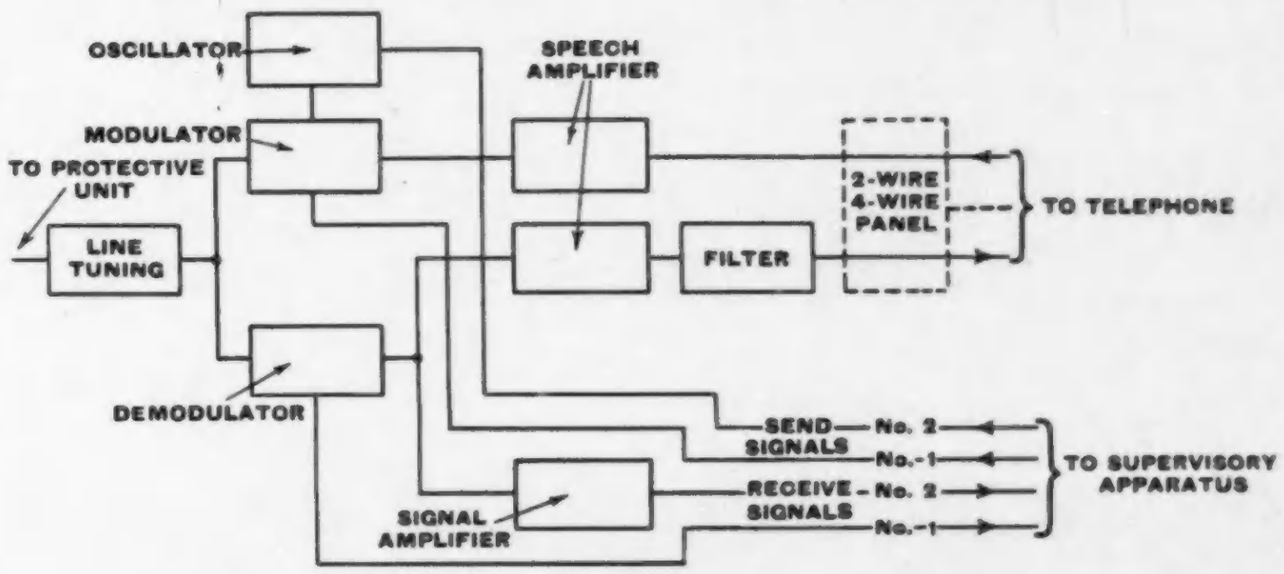


Fig. 18.—Schematic diagram of carrier equipment.

POWER SUPPLIES.

For the operation of the carrier and supervisory equipments, two batteries are provided at each station. They consist of one 24 cell 56 amp-hour battery for supplying the valve filament current and relay currents to the carrier and supervisory apparatus, and an 80 cell 10 amp-hour battery for the valve anode supply to the carrier set.

The power supplies at each station are controlled by power boards, which are illustrated in figs. 7 and 13. Each battery is trickle charged by a rectifier from the local 50 cycle supply, the 24 cell battery by a metal rectifier and the 80 cell battery by a pair of rectifying valves. Smoothing chokes and condensers are provided for each battery to prevent ripples reaching the speech circuits. A "Full Charge" switch is fitted in each case to give a full or booster charge when required, though the trickle charge is adjusted to keep the battery normally in a charged condition.

The 80 cell battery supply has a relay connected across the load terminals which gives an audible alarm should the supply fail for any reason, and a voltmeter and key are provided to measure the voltage across the rectifier output and load terminals.

Two separate loads are taken from the 24 cell battery, one labelled "50V Noiseless," which supplies the valve filaments of the carrier set, and the other labelled "50V Noisy," which supplies all circuits which might create surges, such as relays, selector switches, etc. The circuit for the "50V Noisy" supply passes through an ammeter. A voltmeter and key are provided as for the 80 cell battery. The winding of a contact-making voltmeter is connected across the "Noisy" load terminals, the low and high contacts being set at 50 and 55 volts respectively. These contacts operate relays which give alarms should the voltage fall or rise outside these limits. When giving the battery a full or booster charge, the consequent high load voltage can be counteracted by the operation of keys which tap the load down the battery until the voltage is less than 55 volts, when the "high" alarm ceases to operate.

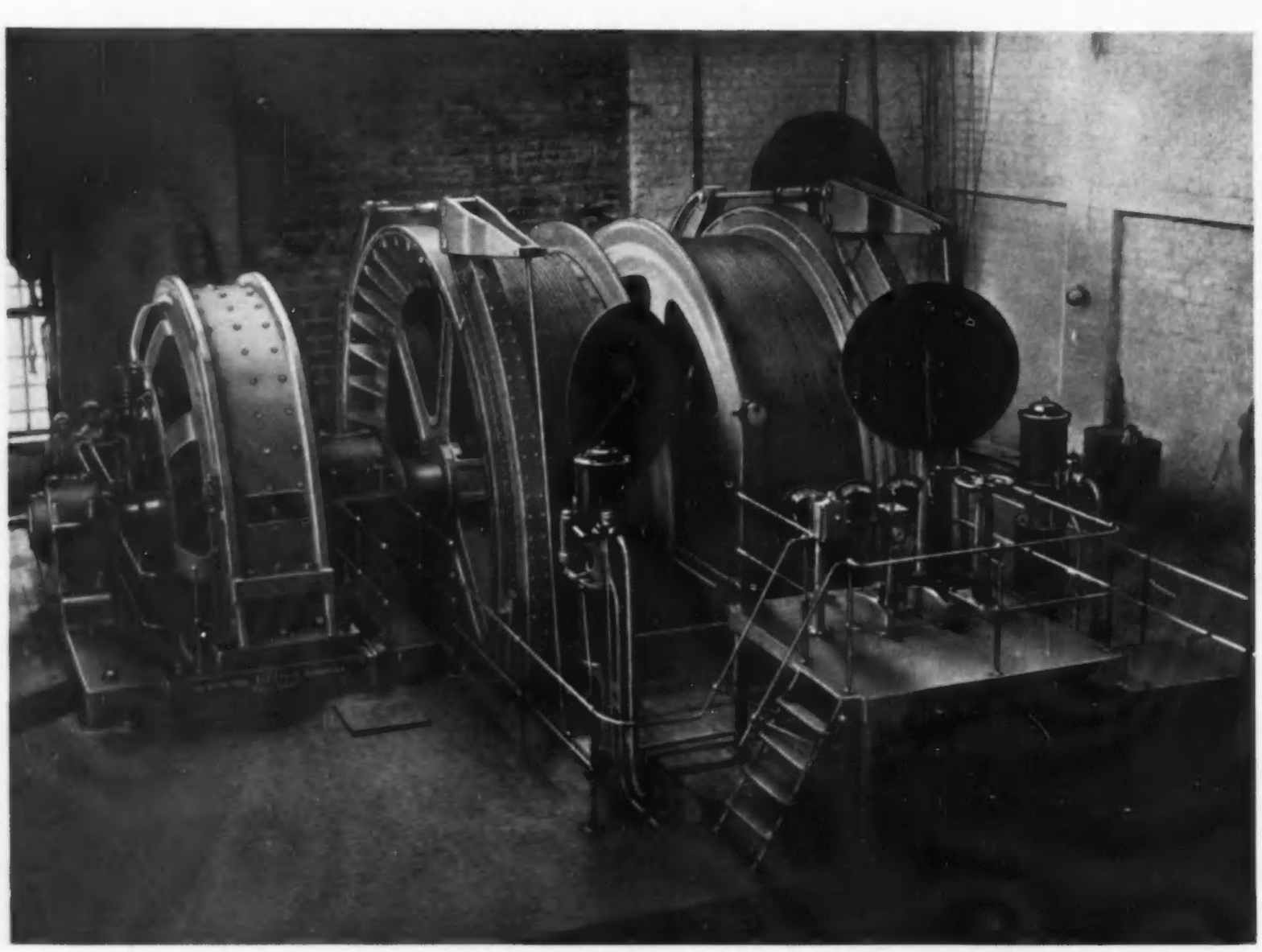
The "50V Noiseless" supply is taken from the battery through an indicating ammeter, a contact-making ammeter and a number of resistances. Since this circuit supplies the valve filaments only, which are all connected in series, constant current,

and not necessarily constant voltage, is required. This is effected automatically by means of the contact making ammeter, whose contacts are set at 0.81 and 0.84 amps. respectively. These contacts operate a series of relays which insert or short out resistances as required to keep the load current between the above limits. This arrangement takes care of variation in battery voltage, changes in the resistance of connecting cable due to variations in temperature, and ageing of filaments.

At Tummel Bridge, where there are two carrier sets, a double-circuit power board is installed. This incorporates two entirely separate 80 cell batteries and trickle chargers, etc., but only one 24 cell 120 amp-hour battery is provided. The load circuits from the latter are divided for the two carrier sets, and each "50V Noiseless" circuit is equipped with a separate automatic current regulator.

Acknowledgment is due both to the Grampian Electricity Supply Co., Ltd., and Balfour, Beatty & Co., Ltd., for their kind permission to publish the information and illustrations contained in this article.

Electric Winder for the Champion Reef Gold Mine, South India.



This illustration shows the erection nearing completion of a 1,200 h.p. 500-volt, 37.5 r.p.m. G.E.C.-Fraser & Chalmers electric winder in the winding house of the Champion Reef Gold Mine, South India. A view of the same winder on the test bed at Fraser & Chalmers' Engineering Works, Erith, Kent, formed the frontispiece of the G.E.C. Journal, February, 1934.

Aerodrome Lighting for Night Flying.

By W. A. VILLIERS, B.Sc.
Exterior Lighting Dept. of The General Electric Co., Ltd.

THE lighting of aerodromes has become of great importance owing to the steady growth in air travel and the carriage of mails by air. It will at once be realised that as the main advantage which the aeroplane possesses over other means of transport is its ability to travel at high speed, air transport is severely handicapped unless flying can be accomplished as safely and easily by night as by day.

It is therefore imperative for the commercial success of aviation, that adequate lighting should be provided at every important aerodrome, and it is proposed in the following article to describe some of the equipment which has been designed by the G.E.C. for this highly specialised form of illumination.

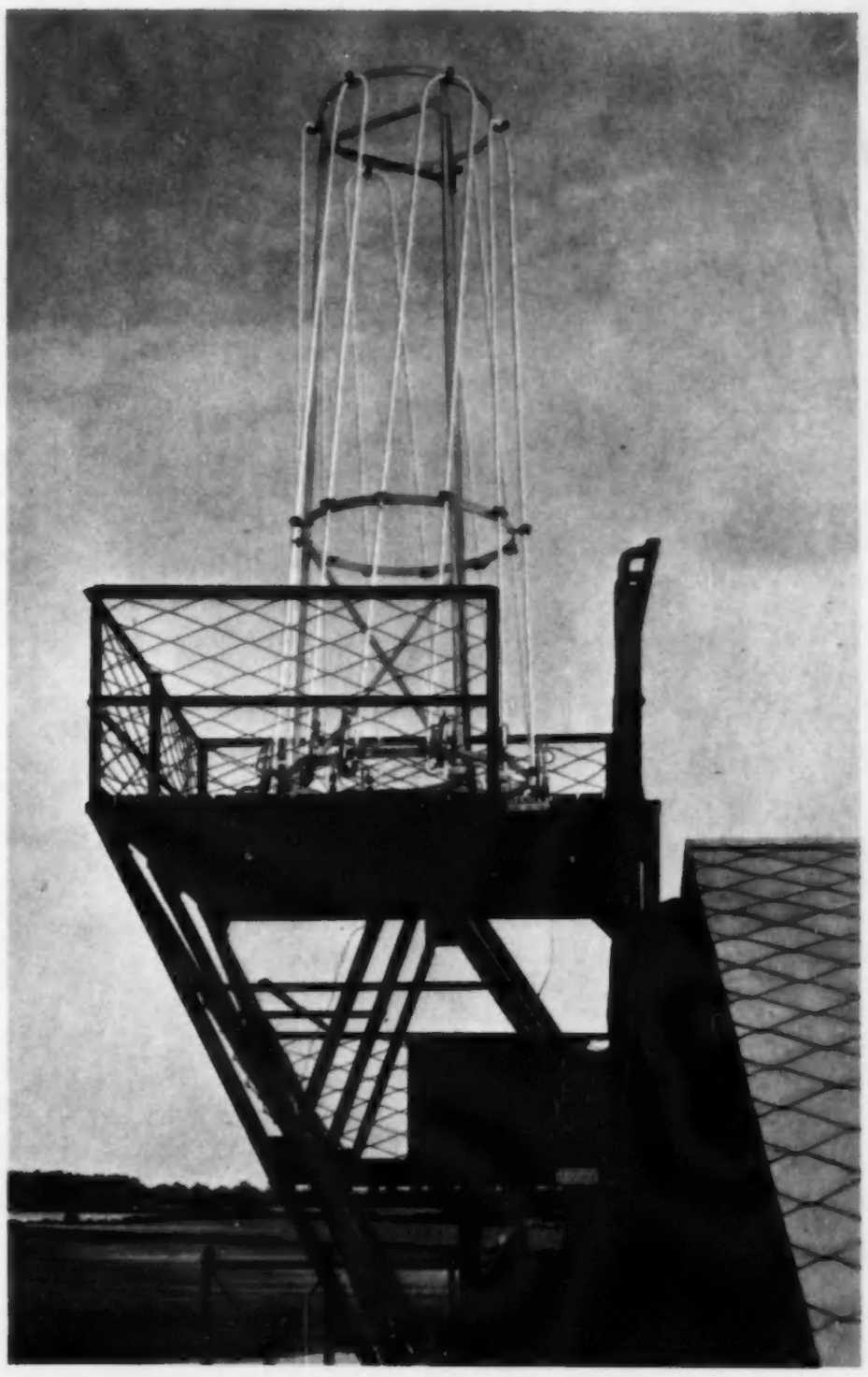


Fig. 1.—Neon aerodrome beacon with transformer case underneath.

A study of the requirements of aerodrome lighting can most conveniently be made by considering the point of view of the pilot of an aeroplane who, it will be assumed, is flying on a dark night to an unfamiliar aerodrome where he wishes to land.

Having arrived in the vicinity of the aerodrome he must discover its exact position and make quite certain as to its identity. The question of identity is important at the present time when aerodromes are in many instances only a few miles apart.

Easy recognition of the aerodrome is achieved by means of a beacon situated close to the landing area. This beacon must give its light through 360° in Azimuth and from the horizontal to the Zenith so that the pilot can readily see it when approaching from any direction and at any height. It must give sufficient light to be visible even in bad weather but the intrinsic brilliancy must be low so that it does not dazzle the pilot when he is gliding in to land.

In addition, the colour and character of the light should be such that the beacon may be readily distinguished from other lights in the neighbourhood and from other aerodrome beacons.

AERODROME BEACON.

These requirements are fulfilled by the neon aerodrome beacon illustrated in fig. 1. It will be seen that the beacon consists of six hairpin shaped neon tubes arranged round a metal framework in the form of a truncated cone about 14ft. high. The light is of the usual red neon colour and of comparatively low intrinsic brilliancy, but owing to the large length of tubing employed, there is sufficient total light flux to ensure that the beacon is easily visible. Under favourable weather conditions it can be seen from a distance of 50 miles.

The tubes are fed with current at high voltage from a bank of three single-phase step-up transformers housed in a weatherproof iron box fixed near the base of the tubing. On normal 3-phase supplies each transformer is arranged to feed two tubes and their design eliminates the necessity of having series choke coils. Three condensers are usually connected across the primary windings of the transformers for power factor improvement, and are housed in the same box as the transformers.

The identification of the beacon is effected by making it flash some morse character such as the initial letter in the name of the aerodrome. The flashing mechanism is included in the low tension side of the A.C. circuit and consists of a triple pole contactor operated through a mercury switch. The latter is tilted for definite periods and at definite

intervals by means of a character disc fixed to a spindle which is rotated by an electric motor.

The times generally allowed for flashing are one second for a dash, one third of a second for a dot and one third of a second eclipse for a space. The time between the end and beginning of the signal when the light is eclipsed is about three seconds.

Fig. 2.—Osram boundary lamp.

A safety governor on the motor shaft ensures that the beacon remains switched on in the event of the motor stopping, while in order to avoid variation of load due to the flashing of the beacon, substitutional resistances are introduced across each phase during the eclipse periods. This is done by providing three additional contacts on the contactor which automatically close the circuit to the resistances when the contacts to the beacon are opened.

ILLUMINATION OF LANDING AREA.

Having arrived at the aerodrome the pilot must next discover the extent and shape of the landing area. These are shown to him by means of boundary lights which are placed round the periphery of the landing ground and spaced 100 metres apart. Each boundary light contains an electric lamp mounted inside an orange glass globe. Thus from the air the landing ground appears to be outlined by points of orange light.

A method of aerodrome boundary lighting which ensures safety in operation has been developed and is known as the constant potential series system, employing special 6.6 volt 600 lumen Osram lamps (fig. 2).

Each lamp is fed from the secondary winding of a small isolating transformer contained in a watertight box placed underground beneath the light (fig. 3). The primary windings of the isolating transformers are all connected in series by a single core ring main and are supplied from a main transformer situated in one of the aerodrome buildings.

There is thus a potential of only 6.6 volts above ground on the aerodrome and as there is no direct electrical connection between the lamps and the mains, the risk of fire and shock are reduced to a minimum in the event of an aeroplane colliding with a boundary light.

The failure of one lamp has no effect on the remaining ones, the isolating transformers being so wound that their impedance on open circuit is approximately the same as when a lamp is connected across the secondary winding.

The housing for the lamp consists of an aluminium alloy casting equipped with an orange glass globe which filters the light so as to give it a hue wavelength between the limits 5940°A and 5980°A. This colour is chosen to distinguish the boundary lights from other neighbouring lights.

Each light is mounted on a 3ft. stem which is screwed into the cast lid of the box containing the isolating transformer. A replaceable weak section is fitted at the base of the stem and breaks if undue pressure is applied to the top of the

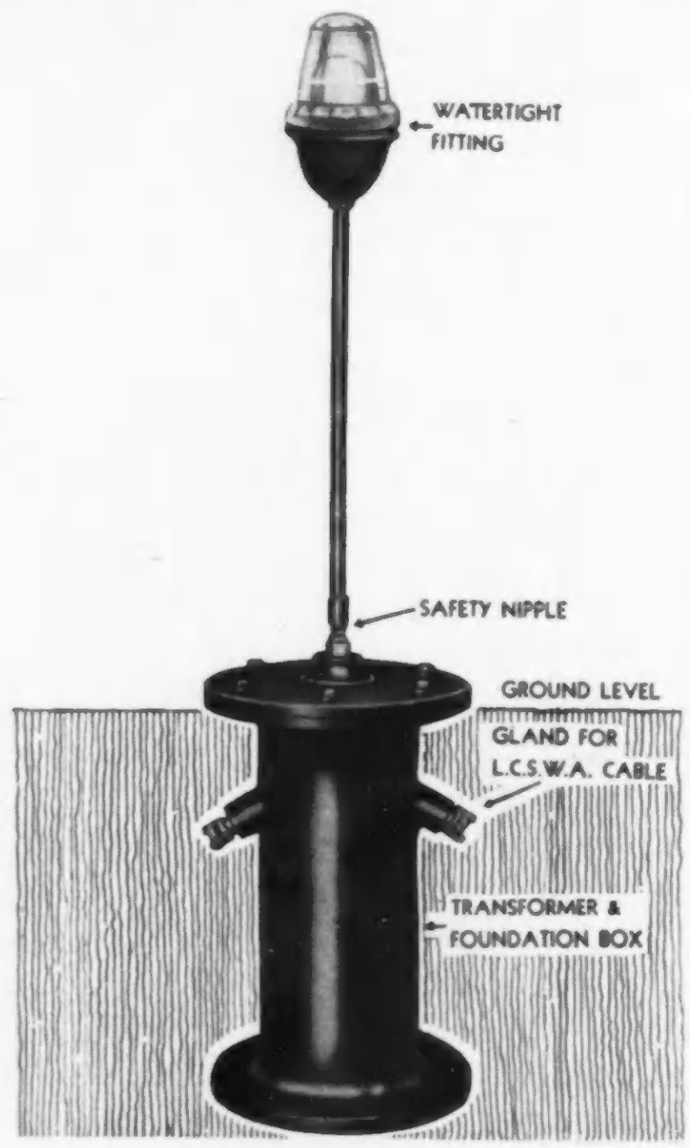


Fig. 3.—Boundary light and isolating transformer box.

boundary light. The purpose of this is to minimise damage if an aeroplane should run into a light.

All the boundary lights may be made if required, to flash simultaneously by means of a rotary cam type flasher, although this is seldom considered necessary.

WIND DIRECTION INDICATOR.

All landings should be made against the wind, because in this direction, not only is the landing safer but the speed of the aeroplane relative to the ground is slower than would be the case were the aeroplane to land in any other direction.

It is therefore necessary for the pilot to ascertain the direction of the wind at ground level before starting his glide. This information is given to him by means of an illuminated wind direction indicator an example of which is illustrated in fig. 5. This equipment gives a clear reading by day or night. It consists essentially of a flat metal T mounted at its centre of gravity on a pivot and having its upper surface painted white. The direct action of the wind on a fin at the tail keeps the T pointing into wind. Both the central stroke and the cross piece are 20ft. long by 2ft. wide and their weight is supported by compression struts so as to leave the upper surface clear of obstruction. The tail fin is fixed on the underside and is of special stream lined section to prevent undue oscillation.

The pivot is constructed of steel tube running in ball bearing and thrust races inside an outer column which also houses the slip rings through which current is fed to the lamps. Access to these sliprings is obtained through a door fitted in the base.

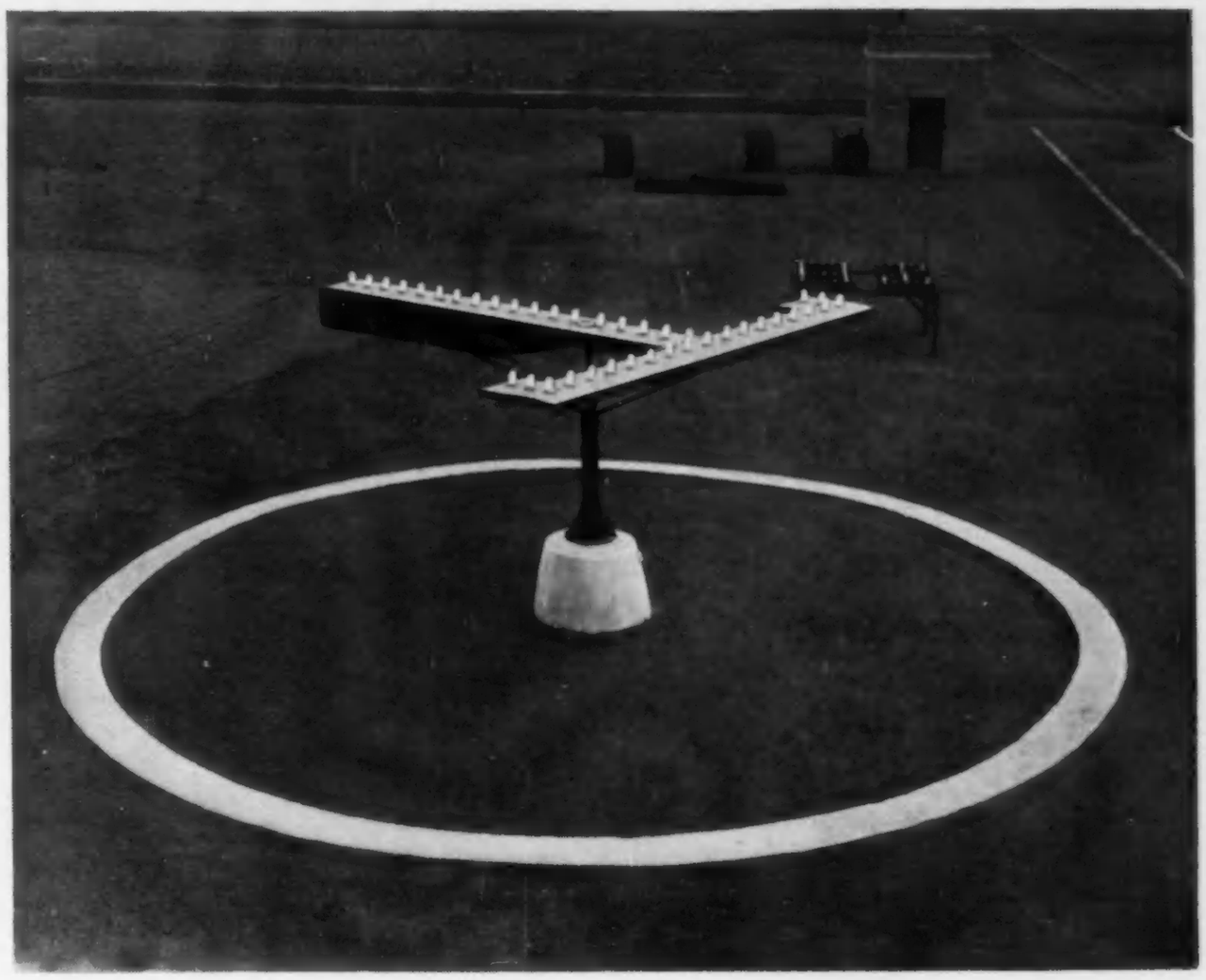


Fig. 5.—Illuminated wind direction indicator.

Fig. 4.—G.E.C. boundary light at Croydon Air Port.

The upper surface of the indicator is equipped with 15 watt lamps spaced 1ft. apart under detachable clear weatherproof glasses. It has been found that 15 watt lamps give the best definition and that higher wattages result in a blurred effect; also that the use of tubular light sources such as neon tubing gives a less clear indication than when point sources of light are employed.

The wind direction indicator should be placed adjacent to the landing area but in such a position that it does not form an obstruction. It should also be in a situation free from wind eddies which occur near buildings or trees.

WIND SPEED INDICATOR.

It is an advantage, though not a necessity, for the pilot to know the approximate strength of the wind so that he can gauge the correct point at which he should turn into wind to land.

A wind strength indicator consisting of a small windmill driving a governor which operates mercury switches connected to an illuminated sign is shown in figs. 6 and 7. The sign (fig. 8) is fixed flat on the ground and has two 6ft. figures which may be changed in a similar manner to the changing programme-number sign in a theatre. The wind strength is shown in steps of 5 m.p.h., such as 0, 5, 10, 15, etc., while the windmill is kept facing into the wind by means of a tail fin, the inertia of the wheel preventing the indication from being effected by gusts. The use of tilting mercury switches in the control gear makes the change definite from one set of lamps to another and eliminates hunting.

OBSTRUCTION LIGHTS.

It is essential that the pilot should have warning of obstructions such as buildings, masts and trees.

Definite regulations have been laid down as to what constitutes an aerodrome obstruction, but generally, all obstacles within the area of the aerodrome and those outside it within a distance less than 500 yards are considered dangerous to aircraft.

Obstruction lights are employed to give warning in this respect and must be visible when viewed from any direction. They must also give a light which is aviation red in colour, of hue wavelength not less than 6100°A. The fitting shown in fig. 9 consists of an iron casting equipped with a detachable red glass globe and containing a 60 or 100 watt lamp. In appearance, except for the colour, it is similar to a boundary light fitting.

Obstruction lights should be duplicated so that in the event of a lamp failure there is still an indication of the obstacle. While they are usually fixed to the obstruction which they mark, in some instances, as in the case of trees, they may be mounted on posts.

LANDING FLOOD LIGHTS.

The last part of the pilot's approach to the aerodrome is the actual landing and to ensure that he makes a good safe landing, the ground should be properly floodlighted with special equipment.

This is a most important part of aerodrome lighting and it is therefore proposed to examine the requirements in some detail.

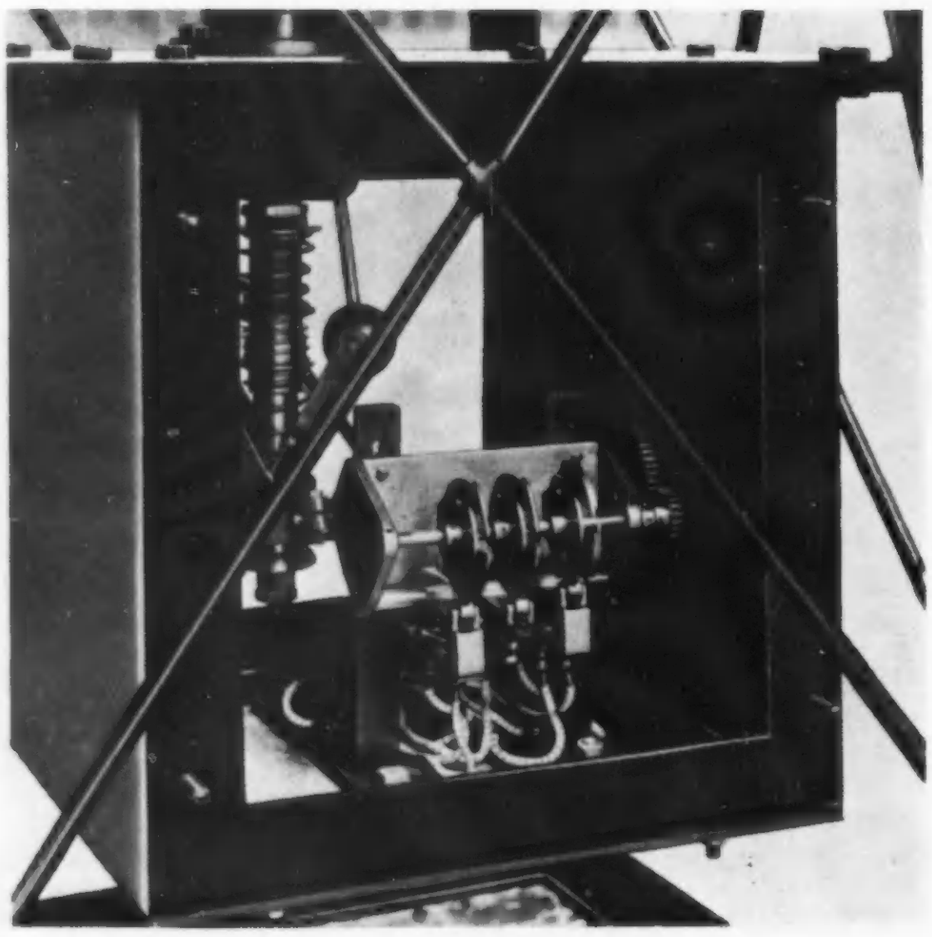


Fig. 6.—Mechanism of wind strength indicator.

The space illuminated must be sufficiently large to enable the fastest aeroplanes to land and complete their forward run without over-running the lighted area. The latter should be roughly square or circular in shape, a convenient size being 2,500ft. by 2,500 ft. The illumination within the lighted area should be not less than .15 foot candles measured on a vertical plane close to the ground.

The floodlight apparatus must be so arranged that no deep shadows are cast by undulating ground

Fig. 7.—Windmill used for determining wind strength.

because from the air these appear as holes in the ground and give a false impression to the pilot. Moreover, the light from the floodlight must be kept below the horizontal as otherwise the pilot would be dazzled when circling the aerodrome prior to landing.

It is essential for safety that the floodlight should be capable of starting up at full power and that there should be no danger of it being suddenly extinguished when an aeroplane is landing; for this reason it is advisable to employ several lamps, for the failure of one of them does not then plunge the aerodrome into total darkness.

Economical considerations dictate that the optical system should be of high efficiency as a very large area has to be lighted and the cable sizes and energy costs must be kept within reasonable limits.

Fig. 8.—Illuminated wind strength indicator.

The 9 kW floodlight shown in fig. 10 contains nine 1,000 watt Osram horizon type lamps having horizontal line filaments arranged at the foci of parabolic trough reflectors. These reflectors are made of optically worked silvered glass and are placed in three tiers one above the other. This particular number of tiers was chosen so that the floodlight could be conveniently connected to an ordinary 3-phase supply, each row of three lamps being on one phase and the total load of 9 kilowatts

Fig. 9.—Obstruction light.

being split up into a perfectly balanced load of 3 kilowatts per phase.

As may be seen from the light distribution curve in fig. 11, the floodlight gives a very wide horizontal divergence of light, but owing to the small diameter of the lamp filaments compared with the focal lengths of the mirrors, the vertical spread is extremely small although a large proportion of the total flux is usefully employed.

An examination of the photographs reproduced in fig. 12 shows a complete absence of upward glare due to the small vertical divergence and the illumination curves, fig. 11 show the high efficiency which is obtained from the optical system.

The maximum beam candles are about 1,200,000 and the isolux curve of equal illumination (fig. 13) is roughly square in shape. The isolux line of .15 foot candles encloses an area of approximately 7,700,000 sq. ft., the whole of which is brightly illuminated, the distance from the floodlight to the furthest point on the isolux line being over 2,800 ft.

The lamps may be focussed in daylight by a simple optical method which ensures great

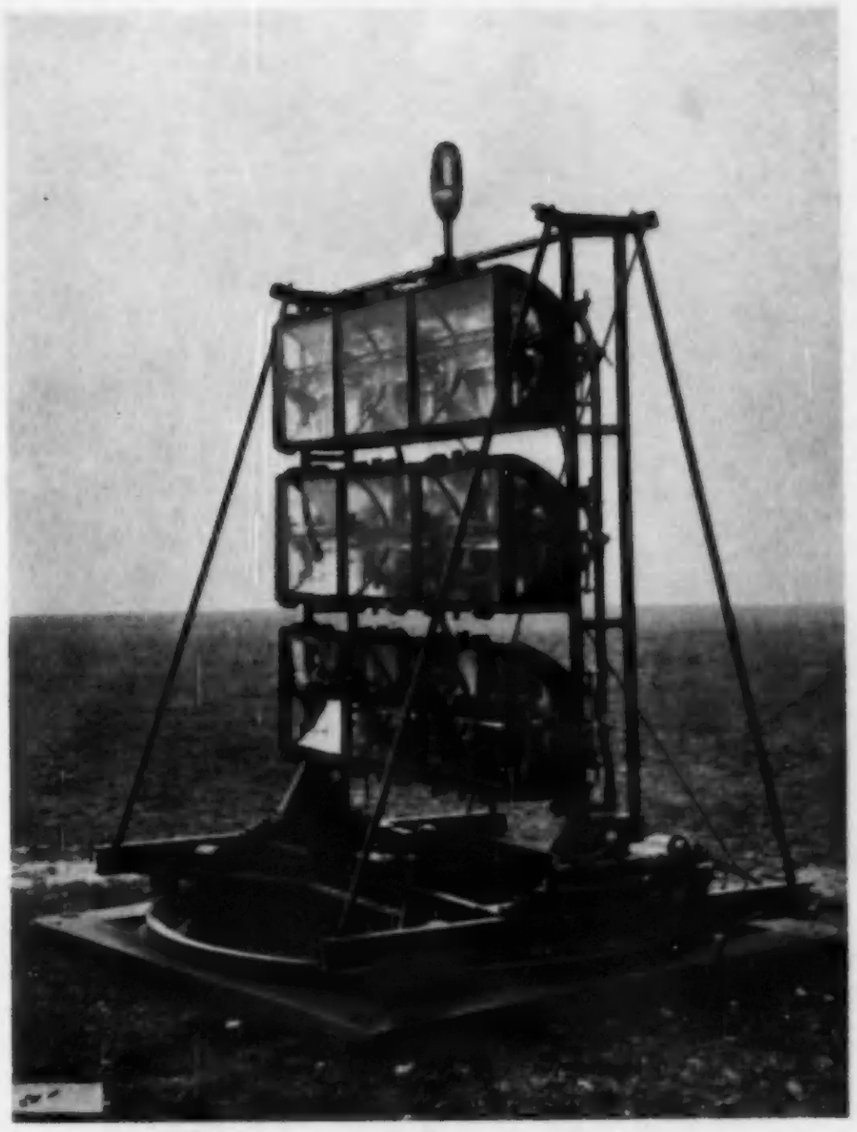


Fig. 10.—9 kW landing floodlight.

accuracy. The lamps are moved relative to the reflectors by means of hand screws until the filament image seen in the mirror coincides with that of a wire stretched across the front of the mirror on a metal frame.

Each row of three reflectors is mounted in bearings and may be tilted at any angle, so that in the case of aerodromes, the landing grounds of which are not absolutely flat, deep shadows caused by bumps in the surface may be eliminated by suitable adjustment of the three troughs.

The floodlight is totally enclosed and non-ventilated, a heat-resisting glass door, which is detachable and secured by hinged hand screws, being provided in front of each lamp. Total enclosure is important as it prevents the ingress of dust, sand and insects and greatly reduces the necessity of frequent cleaning.

A further point of great importance is that the floodlighting system must be arranged so that, whatever the wind direction, the pilot need never land directly in the face of the floodlight.

Three methods of achieving this are as follows:

(1) The floodlight may be mounted on a mobile chassis and moved to any one of several plug points at the edge of the landing area, according to the direction of the wind.

(2) The floodlight may be mounted on a chassis which is also equipped with an engine driven generator and the chassis moved to the most convenient position according to the wind.

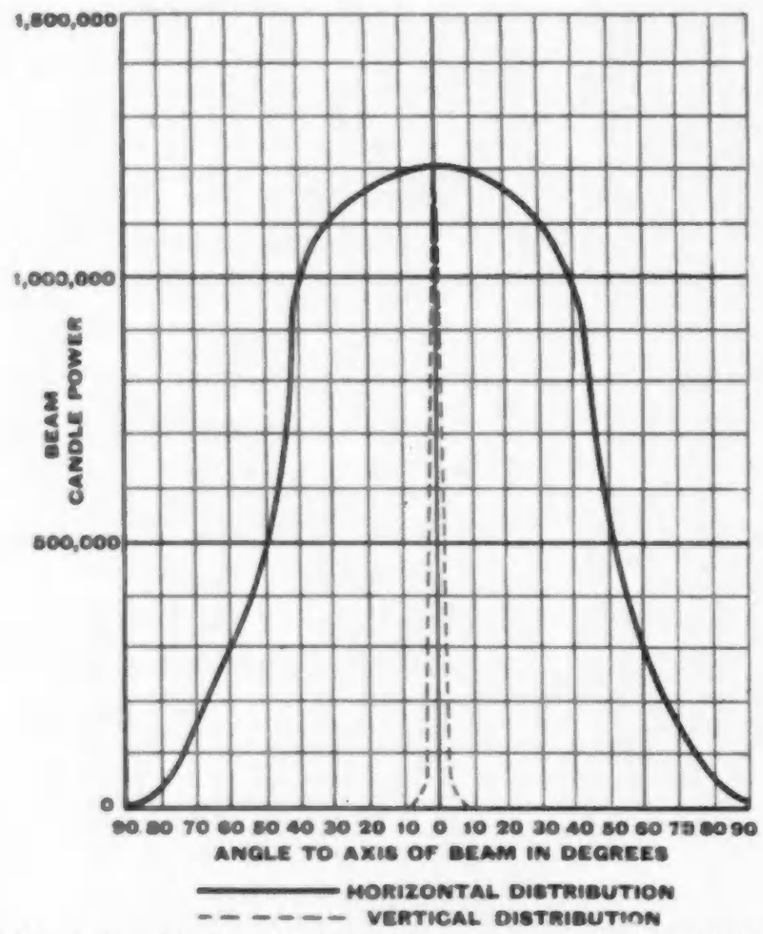

1,500,000
1,000,000
500,000
0
BEAM CANDLE POWER
90 80 70 60 50 40 30 20 10 0 10 20 30 40 50 60 70 80 90
ANGLE TO AXIS OF BEAM IN DEGREES
HORIZONTAL DISTRIBUTION
VERTICAL DISTRIBUTION

Fig. 11.—Light distribution curve of floodlight.

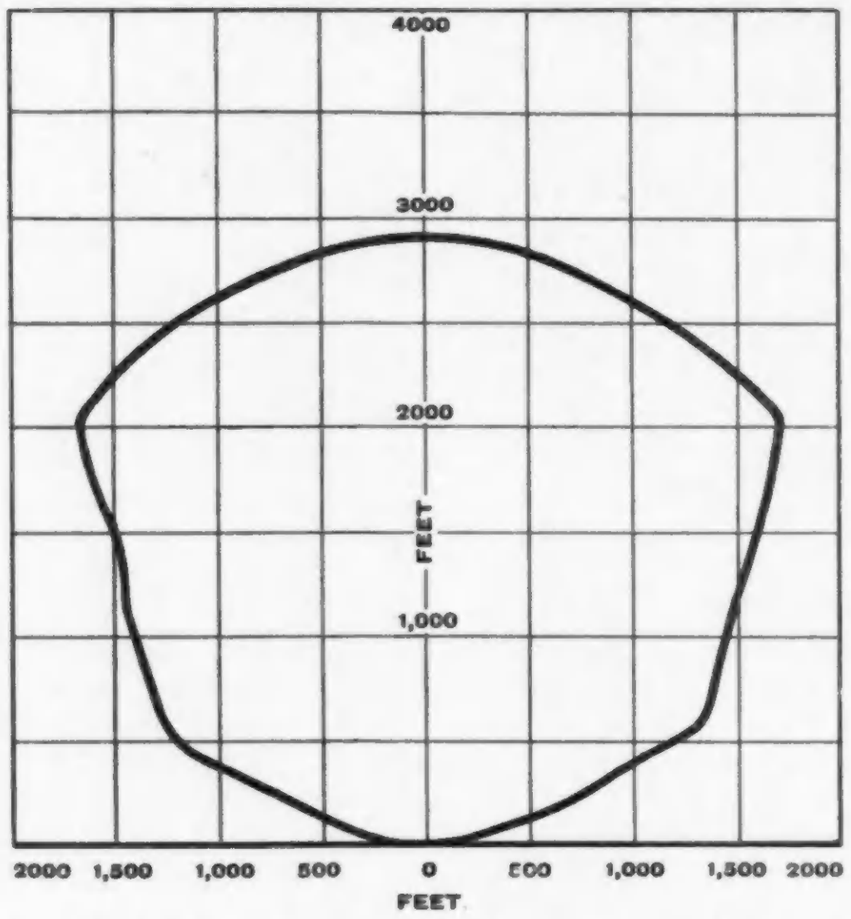
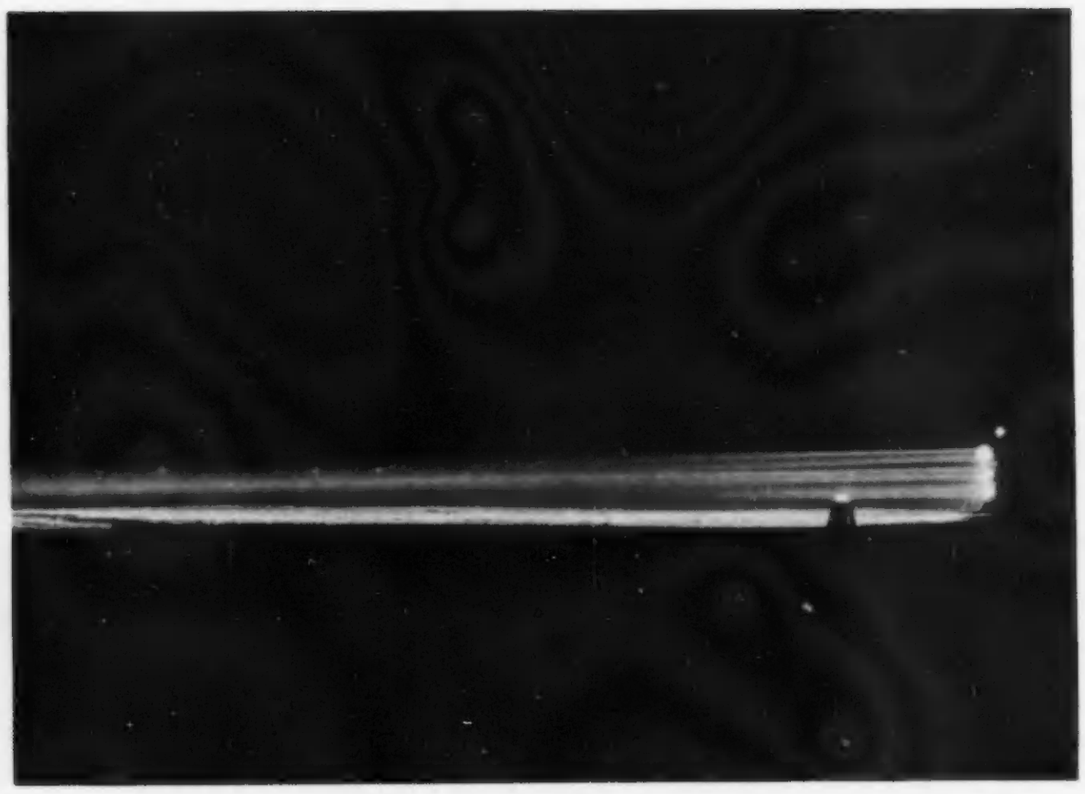


Fig. 13.—Isolux curve showing area included by the isolux line of 0.15 ft. candles measured on a vertical plane. This shows the shape and size of the landing area that is brightly illuminated.

View taken from above and behind the floodlight, showing the illuminated landing area as it would be seen by a pilot prior to landing.



View taken from the side and slightly behind the floodlight, showing the very small vertical divergence.

Fig. 12.—Two night views of G.E.C. 9 kW aerodrome landing floodlight installed at Croydon Air Port.

(3) Two or three fixed floodlights are placed round the periphery of the landing area and one or other is switched on according to the wind direction.

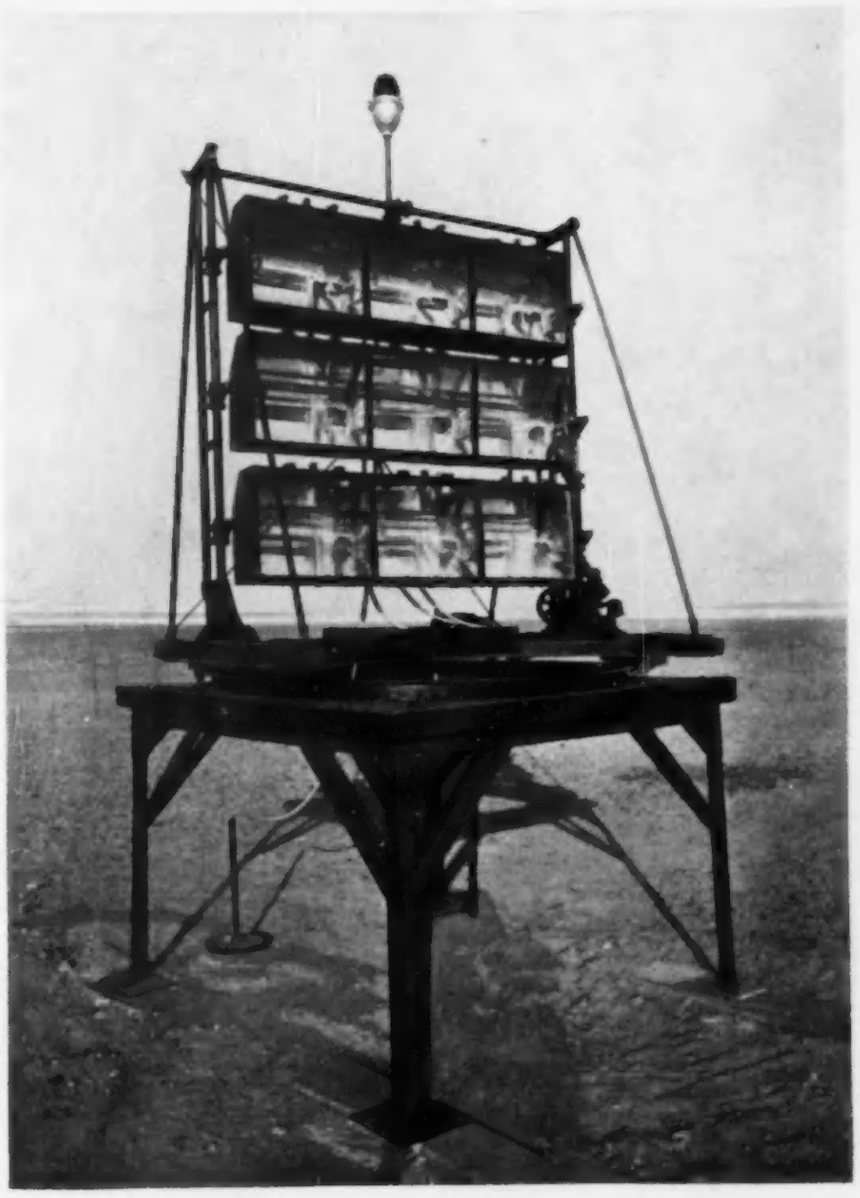


Fig. 14.—9 kW G.E.C. aerodrome landing floodlight installed at Almaza Aerodrome, Cairo.

Fig. 15.—Aerodrome landing floodlight-beacon with shadow bar.

The third method is the most expensive of the three in first cost, owing to the cost of cables, but it is by far the most convenient and should certainly be employed at aerodromes where there is

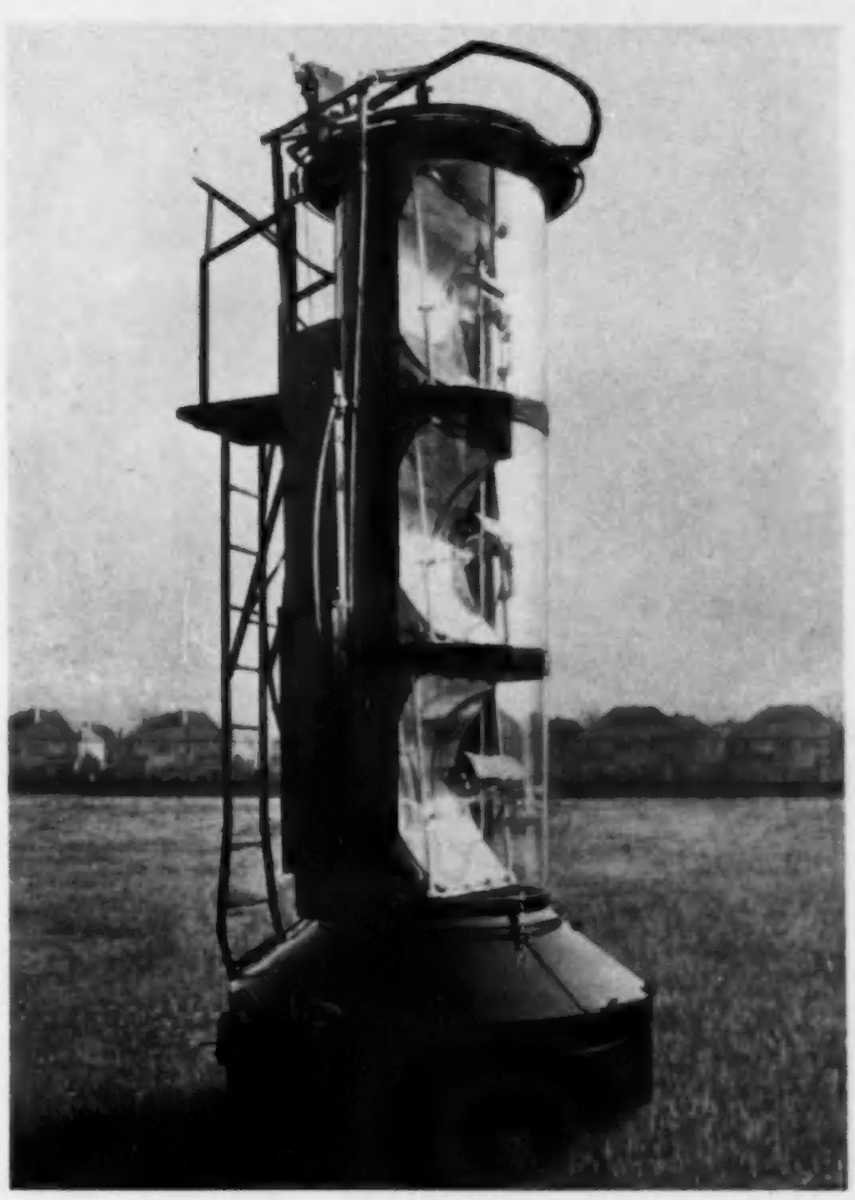


Fig. 16.—9 kW aerodrome landing floodlight with shadow bar folded and mirrors elevated for use as a beacon.

a large amount of night traffic. It is also the most economical in maintenance as it saves the expense of a continually running engine, the moving of the floodlight, and the attendance of an operator.

An entirely different system, which was first introduced in America, is known as the shadow-bar system. It is only recommended for small aerodromes where owing to financial reasons or due to the scarcity of air traffic, it is imperative to keep first costs down to a minimum.

One fixed floodlight only is used, which is placed near to the electric supply so as to avoid the use of long cables. When, owing to the direction of the wind, the pilot has to land in the face of the floodlight, dazzle is prevented by landing in the shadow caused by a moveable bar in front of the floodlight (fig. 15).

The advantage of this system is cheapness; its disadvantages are that a good landing depends on the correct actions of two people, one in the air and the other on the ground moving the shadow bar. Further, it is always necessary to have an operator at the floodlight whenever an aeroplane is landing.

The shadow-bar floodlight illustrated has the same efficient optical system as the standard type

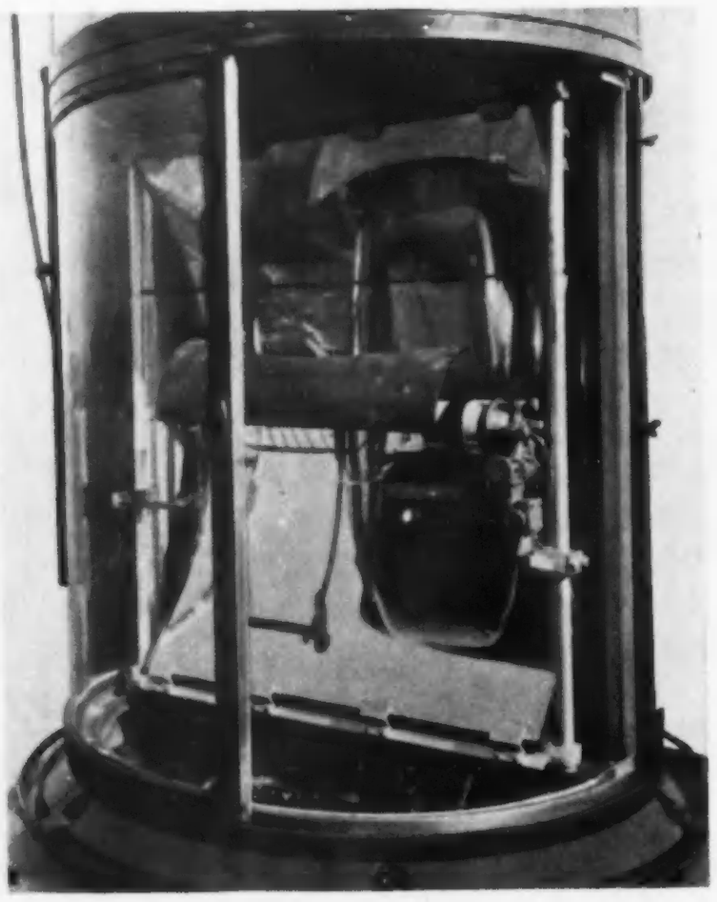


Fig. 17.—Close up view of one compartment, showing mirror, lamp and focussing screws.

but employs three 3 kW lamps with reflectors placed vertically above one another. These are enclosed in a vertical cylindrical housing constructed of brass and copper and fitted in front with sliding half cylindrical glass doors, the whole being weather-proof and dustproof.

The arrangements for focussing the lamps and tilting the reflectors (fig. 17) are similar to those of the 9-lamp floodlight and the same maximum beam candle power of 1,200,000 is obtained. The light distribution curves are almost identical except that the horizontal divergence is not quite so wide.

The shadow bar is constructed of sheet metal and is attached to a 3ft. diameter ring which is pivotted on ball bearings at the top of the floodlight.

The operator stands on a platform at the back of the floodlight and keeps the aeroplane in shadow by steering the ring. The width of the shadow is about 36ft. at a distance of 500ft. from the floodlight.

This floodlight may also be used as a beacon and for such cases is equipped with a $\frac{1}{2}$ h.p. motor with clutch and gearing inside a cast base.

When operating as a beacon the shadow bar is folded and clamped against the side of the housing (see fig. 16) which is then revolved by the motor at a speed of 11 r.p.m. Simultaneously, the mirrors are tilted upwards so as to give the correct light distribution for a beacon.

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